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THE JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY

CONTENTS **JUNE 1952**

SECRETARY'S NEWS LETTER AND NOTICES

THE AVAILABILITY AND USE OF AERONAUTICAL INFORMATION —A DISCUSSION

FATIGUE OF AIRCRAFT MATERIALS WITH SPECIAL REFERENCE TO MICRO-STRUCTURE
P. L. Teed, F.R.Ae.S.

DESIGN PROBLEMS FOR INTERCEPTOR FIGHTERS
Lt. Cdr. J. S. Bailey, O.B.E., R.N.

PROBLEMS OF SHORT-HAUL AIR TRANSPORT
P. W. Brooks, B.Sc., A.C.G.I., A.F.R.Ae.S.

NOTES ON THE MEAN AERODYNAMIC CHORD AND THE MEAN AERODYNAMIC CENTRE OF A WING
A. H. Yates, B.Sc., A.F.R.Ae.S.

ADDITIONS TO THE LIBRARY CORRESPONDENCE

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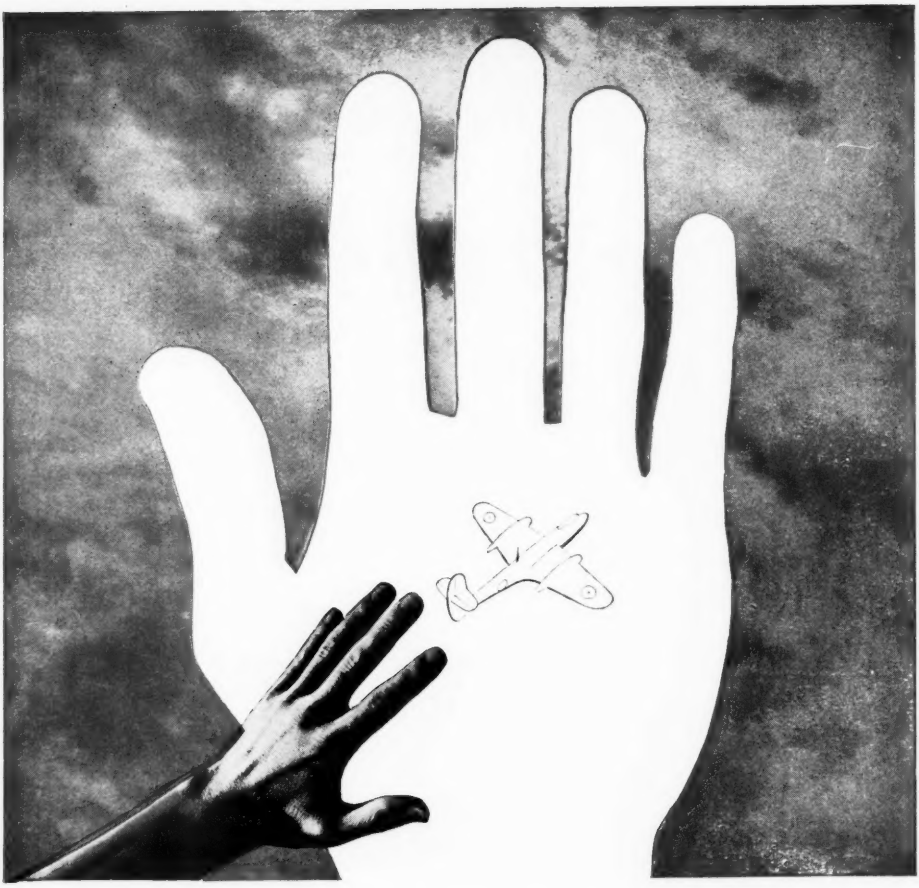

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Mr. Dowty has had a long association with the Society, having been elected a Student member in 1918, an Associate Fellow in 1926 and a Fellow in 1937. He was a Vice-President of the Society and a member of a number of Committees, including the Future Policy Committee, Finance Committee and the Journal Committee.

He is an Associate Fellow of the Institute of the Aeronautical Sciences of America, and was one of the Founder Members of the Institution of Aeronautical Engineers which was amalgamated with the Society in 1927.

Mr. Dowty was educated at the Royal Grammar School, Worcester, and during the years 1916 to 1931 was with Heenan and Froude, Worcester; British Aerial Transport Company, Willesden; T. Cook and Sons, York; the Dunlop Rubber Co.; A. V. Roe and Co.; and Gloster Aircraft Ltd.

He has been concerned with the development of undercarriages since about 1922 and was the inventor of one of the early deck-landing arresters developed in this country.

In 1931 he founded his first Company with one man, and is now Chairman and Managing Director of Dowty Equipment Limited and other associated Companies in this country and Overseas, employing many thousands of people.

G. H. Dowty, *Fellow*
President 1952-1953

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Secretary's News Letter

JUNE 1952

At the Annual General Meeting on the 7th May Major F. B. Halford retired from the Presidency, and Mr. G. H. Dowty became President.

Major Halford has had a very difficult year, due to his illness, but he was able to finish, as he began, strongly. At the A.G.M. he thanked all those who deputised for him; I should like to add my personal thanks to the three retiring Vice-Presidents, Mr. S. Camm, Mr. G. R. Edwards, and Mr. G. H. Dowty, and also to Major G. P. Bulman and Air Commodore F. R. Banks, who answered my often last-minute calls for a Chairman.

Elsewhere in this issue there is a photograph of the new President, and a short biographical sketch. We wish him a very successful year of office.

Council have decided to sponsor the foundation of a film register of aviation films, and arising from this, to commemorate the 50th Anniversary of Power Controlled Flight by the compilation of a film showing the history of Aviation over the past 50 years. As a first step towards this film I desire information on what films exist and where they are to be found. If any individual or firm possesses *any* film on Aviation I should be pleased if they would write to me and give me full particulars under such headings as

(*a*) Subject.
(*b*) Gauge—16 mm. or 35 mm.
(*c*) Length
(*d*) Print or negative
(*e*) Black and white or colour
(*f*) Date taken
(*g*) Condition
(*h*) Made by
(*i*) Copyright
(*j*) Availability
(*k*) Silent or sound.

I know there is a vast amount of film in existence; it will be impossible to use all the material available for this film, but the register will contain all the material from which the 50th Anniversary film can be made.

During the past months the Council have been considering the publications of the Society, and after much deliberation have decided to make some few alterations.

Beginning January 1953 it is hoped to change the size of the JOURNAL from its present page size of 8 in. by 5½ in. to a page 11 in. deep by 7 in. wide. This will result in a better Journal all round, especially in make-up. Of this I shall write later in the year.

The Aeronautical Quarterly also came under discussion. Council decided that the QUARTERLY would be published only twice a year for the next two years, and then the position would be reviewed in the light of the experience gained during this trial period. There is no doubt that *The Aeronautical Quarterly* fulfils a definite need, for the media open to this type of paper are very limited in number.

I am rather disappointed at the support given by members of the Society to *The Aeronautical Quarterly*, and I find it difficult to assess the reason. Whatever the reason I hope that the QUARTERLY will be better supported in future. An application form is enclosed with this Journal.

The article on "Photoelasticity" by Jessop and Snell, published in the QUARTERLY (Volume III, Part 3) aroused considerable interest among the members of the Structures Committee. As a result of this, a demonstration of Photoelasticity was arranged at the Department of Civil Engineering, University College, London. It was given by Colonel H. T. Jessop. The Committee was later entertained by Professor H. J. Collins.

It was a very instructive visit; it showed that there were considerable potential uses of this technique in the Aircraft Industry.

A. M. Ballantyne

Secretary

NOTICES

COUNCIL FOR 1952-53

The Council for 1952-53 is as follows:

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G. H. Dowty (*Fellow*)

Past Presidents

Major F. B. Halford, C.B.E. (*Fellow*)
Major G. P. Bulman, C.B.E., B.Sc. (*Fellow*)
Sir John S. Buchanan, C.B.E. (*Fellow*)

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G. R. Edwards, M.B.E., B.Sc. (*Fellow*)

Ordinary Members

Air Commodore F. R. Banks, C.B., O.B.E. (*Fellow*)
Professor A. R. Collar, M.A., D.Sc. (*Fellow*)
E. B. Dove (*Associate*)
W. S. Farren, C.B., M.B.E., M.A., F.R.S. (*Fellow*)
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S. Scott Hall, C.B., M.Sc., D.I.C. (*Fellow*)
N. J. Hancock (*Associate Fellow*)
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Capt. J. L. Pritchard, C.B.E. (*Hon. Fellow*)
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J. G. Roxburgh (*Graduate*)
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Solicitor: L. A. Wingfield, M.C., D.F.C. (*Associate*)

Secretary: Dr. A. M. Ballantyne, T.D. (*Associate Fellow*)

Note: The Vice-Presidents are elected at the May Meeting of the Council.

GARDEN PARTY, 15th JUNE 1952, WHITE WALTHAM AERODROME

Will those members who have not yet applied for their tickets for the Garden Party do so as soon as possible please, in order to help with the organisation.

This year there will be a number of personal and training aircraft from this country and abroad, a number of helicopters and an interesting gliding display. Some of those taking part in the gliding display will be leaving shortly afterwards for the International Gliding Contest in Spain, so this will give members an opportunity of seeing them before they leave.

The tickets are 10s. each, including tea and car park, and the coach tickets are 10s. each. Tickets for the Garden Party and the coach must be obtained from the offices of the Society. An application form for home members is enclosed with this Journal.

ANNUAL GENERAL MEETING

The Annual General Meeting of the Society was held at 4 Hamilton Place, W.1, on 7th May 1952, at which the Annual Report and Balance Sheets of The Royal Aeronautical Society and Aeronautical Trusts Ltd. for 1951 were approved. The complete Report and Balance Sheets were published in the April 1952 JOURNAL.

The following elections were announced at the Annual General Meeting:

Fellows

F. S. Burt
A. V. Cleaver
L. G. Fairhurst
R. H. T. Harper
W. F. Hilton
R. C. Morgan
H. C. Smith
R. H. Weir.

CONTENTS OF THE JUNE JOURNAL

Secretary's News Letter and Notices.
The Availability and Use of Aeronautical Information—A Discussion.
Fatigue of Aircraft Materials with Special Reference to Micro-Structure, P. L. Teed, F.R.Ae.S.
Design Problems for Intercepter Fighters, Lt. Cdr. J. S. Bailey, O.B.E., R.N.
Problems of Short-Haul Air Transport, P. W. Brooks, B.Sc., A.C.G.I., A.F.R.Ae.S.
Notes on the Mean Aerodynamic Chord and the Mean Aerodynamic Centre of a Wing, A. H. Yates, B.Sc., A.F.R.Ae.S.
Additions to the Library. Correspondence.

(An annual sum of £250 is available for premium awards for papers published in the Journal. These premium awards are usually 15 guineas each. Members and non-members of the Society are invited to submit papers on any aspect of aeronautics.)

THE AERONAUTICAL QUARTERLY—VOLUME III, PART IV

The Aeronautical Quarterly, Volume III, Part IV, February, is available from the offices of the Society, at 7s. 6d. a copy to members (7s. 9d. post paid) and 10s. (10s. 3d. post paid) to non-members.

The contents of Part IV are:—

The Automatic Control of an Aeroplane in the Landing Approach onto an Aircraft Carrier ... ... J. B. Helliwell
Supersonic Flow over Thin Symmetrical Wings with given Surface Pressure Distribution ... ... F. A. Goldsworthy
Longitudinal Waves in Beams ... ... R. E. D. Bishop
A Note on Supersonic Wing Integral Equations in Unsteady Flow ... ... John W. Miles
The Theory of Aerofoils in Unsteady Motion ... ... J. R. M. Radok
Index to Volume IV.

Copies of Volume III, Parts I, II and III, are still available from the offices of the Society at 7s. 9d. a copy to members of the Society, post paid, or 10s. 3d. to non-members, post paid.

SOCIETY OF BRITISH AIRCRAFT CONSTRUCTORS' EDUCATIONAL GRANTS

The attention of members is drawn to the Society of British Aircraft Constructors' Educational Grants administered by the Society.

The Grants are designed for the assistance of young men who are unable, for financial reasons, to obtain training in aeronautical engineering. All holders of S.B.A.C. grants are expected to qualify for a technical grade in the Royal Aeronautical Society.

Applicants should be between the ages of 16 and 18 on 1st September in the year of the award. The closing date for applications for this year is 30th June 1952. Application forms may be obtained from the Secretary.

MEMBERS' NEW APPOINTMENTS

A. NEVILLE BARBER (*Associate Fellow*) has been appointed head of the Technical and Design Section, Engineering Department, of Hatfield Technical College.

D. W. BRINKWORTH (*Associate Fellow*) has been appointed Design Engineer of the Lockheed Aircraft Corporation of Burbank, California, as from 14th May 1952.

P. G. CRABBE (*Fellow*) has been appointed Managing Director of Gloster Aircraft Limited.

A. MURASZEW (*Associate Fellow*) has been appointed a senior development engineer in charge of fuel systems for gas turbine engines at A. V. Roe (Canada) Ltd.

A. G. P. VAUGHAN (*Graduate*), formerly of Armstrong Siddeley Motors Ltd., is now engaged on work concerned with Guided Weapons for I.C.I. (Metals Division) at Summerfield Research Station, Kidderminster.

R. J. B. WOODHAMS (*Associate Fellow*) has been appointed Chief Designer to Air Service Training Ltd.

HONOURS AWARDED TO MEMBERS

Dr. KENNETH G. BERGIN, M.A., M.D., D.P.A. (*Associate Fellow*), B.O.A.C. Regional Medical Director, was among the ten new Fellows of the Aero Medical Association elected as "having made outstanding contributions to aviation medicine." Dr. Bergin has also been asked to give a paper at the meeting of the British Association for the Advancement of Science which is to be held in Belfast in September.

ERIC MENSFORTH, C.B.E., M.A., M.I.Mech.E. (*Fellow*), has been elected President of the Helicopter Association.

Sir DAVID PYE, C.B., M.A., Sc.D., F.R.S. (*Fellow*), has been elected President of the Institution of Mechanical Engineers.

DIARY

LONDON.

June 15th.
Garden Party. White Waltham Aerodrome, near Maidenhead, Berks. 2.30-6.30 p.m. (*See special notice.*)

BRANCHES.

June 9th.
Halton—Flying Boats. H. Knowler. Branch Headquarters. 6.45 p.m.

June 16th.
Glasgow—A History of Aeronautics in Scotland. I. R. Liddel. Royal Technical College. 7 p.m.

June 23rd.
Halton—Films. Branch Headquarters. 6.45 p.m.

July 7th.
Halton—Air Photography in War and Peace. Group Captain F. C. V. Laws, C.B., C.B.E., F.R.P.S. Branch Headquarters. 6.45 p.m.

ELECTIONS

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

Alan Farrer Barker (*from Graduate*)
Robert Henry Matthews Bennett
Albert Norman Bland
Henry Eccarius Bolton (*from Associate*)
Peter Brett (*from Graduate*)
James Robert Clapham
Graham Victor Cowmeadow
Vivian Ernest Cooksey Forster
Thomas George Frederick Hardy
Eric Fred Hill (*from Associate*)
Peter Athelwold Pennant-Rea (*from Associate*)
Lionel John Charles Petts
James William Warris
Ralph Leonard West
Leslie Colin Woods (*from Graduate*)

Associates

Alfred William Bedford
John William Johnson
Joseph Andrew Matthews
George Desmond Antony Rignall
Clive King Saxelby
Nicholas Charles Rupert Sinnott
Kingsley Newman Smith

Graduates

Maurice Sidney Binning
Roderick Douglas Dale
Peter John Elmes (*from Student*)
Gordon Esilman (*from Student*)
Jose Edouard Godts
Graham Hills (*from Student*)
Ernest Edgar John Horney
Raoul Gery Edward Mallin (*from Student*)
James Alfred McMorran
David Thomas Anthony Miller (*from Student*)
Peter Alexander Michael Perry
William James Redstone (*from Student*)
John William Storer
Alexander Syme (*from Student*)

Students

Arthur Laurence Barbrook
Norman Arthur Barfield
Peter James Bashford
Henry Alan Gura
Dennis Charles Jackson
William Edward Littleboy
Dilip Kumar Ray
David Edward Rayner
Jibesh Sen
M. A. Tirunarayanan

Companions

Dudley Sandry Garton Honor
Derek Norman James
Pierre Julien
Albert Wallace Laughton

ACKNOWLEDGMENTS

The Council acknowledge with grateful thanks the return of back numbers of the JOURNAL from F. T. Bevan, Esq., *Associate Fellow*, and C. D. Allen, Esq. (*ex-Student*).

JOURNAL BINDING

Members are reminded that a special leaflet on JOURNAL binding for the 1951 Volume and for 1952 was enclosed with the December JOURNAL. Copies of this leaflet are available on application to the Society.

CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).

Grade of membership.

New address (in block letters).

Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the JOURNAL for the following month.

Availability and Use of Aeronautical Information

A DISCUSSION

A joint Discussion was held by the Royal Aeronautical Society and the Association of Special Libraries and Information Bureaux (Aslib) on the 7th February 1952 at the Institution of Civil Engineers, Great George Street. Mr. A. A. Hall, F.R.Ae.S., Director, Royal Aircraft Establishment and a Member of Council of the Society, presided and introduced the Discussion.

At the opening of the meeting the Chairman expressed sincere sympathy with the Royal Family and the deep sense of loss of the whole Commonwealth and Empire in the death, on the previous day, of His Majesty King George VI—Patron of the Society. The meeting stood in silent tribute.

The Chairman (A. A. Hall, *Fellow*): The value to be obtained from using existing information rather than continually turning over the ground was manifest, particularly at a time when the volume of information appearing was so large. That was true of all branches of science, and two or three years ago the Royal Society had called an international meeting, which had done a good deal of useful work. But a complete answer had not yet been obtained. On this occasion he asked that the discussion be confined to aeronautical information.

There were two aspects of the problem. The first was keeping people up-to-date and their knowledge fresh in the light of other people's discoveries. The second was providing data quickly when it was required on a particular subject for a particular technical purpose. Those two aspects were obviously inter-related, but to some extent they could be separated; and he would put his questions in those two separate categories.

There were many well-established means of keeping people up-to-date, and enlightening them about what was going on; examples were abstracting journals and data sheets. One of the questions which must be examined was whether there were sufficient readily available means for the dissemination of existing information, and what were the shortcomings of those facilities which did exist.

It was clear that, however good the existing facilities might be, they were open to improvement. Everyone who used the various means available had felt, at any rate on occasions, some degree of dissatisfaction with them. The meeting hoped to hear proposals for improvement.

There were two or three factors which impinged on the matter and made the keeping of people up-to-date a difficult process sometimes. First there was the question of security. They would need the help of experts on that matter; but he did not think it was one to be flogged.

A second factor was the impact of the dissemination of information on commercial rights. They should examine what tendency there might be to withhold information on the grounds of its possible commercial utilisation and the extent to which they must take account of that quite reasonable aspect in deciding how best to deal with information that came out.

Foreign information also created a problem. It was much easier to handle information within the national boundaries than to handle foreign information, and there was undoubtedly a distinct gap in the business of letting people know what had been done and what was available abroad.

On the provision of specific data to meet a technical need it was open to question whether existing services were adequate, first in the time taken to get the data to the technical men who wished to have it, and secondly in the completeness of the data when it was received. One of the problems for debate was the need for some common coding system which would enable the needs

of the technical worker to be coded and indexed quickly. It was reasonable to suppose that no information service could hope to keep everything. They would look rather to an arrangement within which information services were mutually helpful and the needs of the users were met from a series of sources. That undoubtedly required some common coding system.

It was worth remembering that in America a Central Government bureau had been set up with that kind of purpose in mind. It was a large organisation which sought centrally to be able to satisfy all needs, feeding things out to the various branch services. There was no such organisation in Great Britain, and it was worth considering whether there ought to be and whether that was the best way of dealing with the problem.

Another direction in which discussion might be fruitful was to hear of experience, particularly with the Universal Decimal System, which was in current use in many libraries, but was nevertheless open to criticism. It would be interesting to hear how the people who were handling those matters had coped with the system and had tried to fill in the gaps.

Again, it would be extremely interesting to hear proposals for new coding systems, new organisations and new channels of information, which would reduce the time required to get information together and to ensure its reasonable completeness.

If they accepted that the use of information was of high commercial value and enabled them to avoid spending a lot of money in doing work over again, and if indeed it was worthy of serious consideration on the organisational side, then the question of how the organisation was staffed was also worthy of careful consideration. In many cases insufficient attention was paid to getting suitably qualified staff to handle the problems of getting information together and keeping people up-to-date. Aslib was one organisation which would assist, and it would confirm that the task required staff of high calibre and high qualifications.

A discussion such as this was a fruitful source of trouble and strife concerning symbols of one kind or another. While he did not wish to rule out discussion of it altogether, he suggested that it should not be discussed at length. The discussion should be concerned mainly with the two questions of how to distribute knowledge as it "came off the press" and how to get specific information when it was required—appreciating full well that no man or woman could keep everything in mind for very long.

Cyril Cleverdon (Librarian, College of Aeronautics): Some definition was necessary for the title of the discussion—The Availability and Use of Aeronautical Information. In the term "use" were included those devices whereby a person working on a particular subject was kept advised of all new information about it; and it also included the methods by which all information on a particular subject could be made readily available. The latter task was achieved by means of classification schemes and bibliographies, and as such was purely the concern of the librarian. To keep a person regularly informed was again the concern of the librarian, but also of others. In its simplest form the task could be performed by title-lists, but more usually it involved abstracts and also, possibly, summaries or data sheets. The preparation of data sheets or even abstracts meant that a person who was capable of doing creative work in a subject was devoting his time to a task which would give his colleagues more time for original work.

"Availability," in its ideal sense, implied that a full size copy of a report could be on the desk of the person who wished to read it. The next stage in availability was that there should be a microfilm or microcard of the report which could be consulted with the aid of a reader located in the building. Then came the case where an engineer in Manchester required a copy of a report which was in London. Whether or not it could be considered as being available depended on whether it was required immediately or could be transferred from London to Manchester in time to be of value to the user. The limit of availability was reached when a required report had to be obtained from abroad. The situation was more or less the same if a copy were in the country but its existence was unknown to any library.

Availability was largely an administrative matter. With periodicals and reports published in the United Kingdom there should be little or no difficulty. With foreign periodicals the question of cost was of some importance, but it was really a matter for each individual organisation to decide for

itself. It was with foreign reports that they met the real difficulties.

A considerable amount of important work was being published in the Commonwealth and in many European countries, such as France, Sweden, Switzerland, Italy and the Netherlands, but the number of reports issued by all those countries together was only a small fraction of those which appeared in the United States. Dr. Compton, formerly Chairman of the U.S. Research and Development Board, had estimated that some 450,000 reports were issued annually in America, of which 80 per cent. were pertinent to the science of aeronautics.

With foreign reports, particularly those from America, there were three distinct problems. First, to discover that a report had been written; next, the problem of obtaining a copy in this country; and finally, seeing that everyone concerned was aware that a copy was available.

At present various Government organisations received certain American reports, including the Ministry of Supply, the Admiralty, and the Technical and Information and Documents Unit of the Department of Scientific and Industrial Research. In addition, many other organisations, by purchase, by exchange or through personal contacts, received reports issued by universities, aircraft firms, airlines, private research organisations and learned societies. At present all this was quite un-co-ordinated, with the result that, except for well known series of reports, such as N.A.C.A. publications, no librarian could be certain whether or not any American report was available in Great Britain.

There was an acute shortage of persons qualified to undertake the various duties concerned with the availability and use of aeronautical information. Obviously, if money and man-power were freely available, it would be pleasant for every organisation to prepare its own abstracts and maintain its own index of the thousands of reports and periodical articles that appeared every year. But in any circumstances that would be a wasteful procedure, and in present conditions it was impracticable.

That problem had arisen even in America, and as a result four major organisations—the Atomic Energy Commission, N.A.C.A., the Navy Research Section and the Central Air Documents Office—had combined to form the Armed Services and Technical Information Agency, usually known as Astia. In the directive dated 14th May 1951, signed by General Marshall when setting up that organisation, the duties of Astia were stated, as follows:—

(*i*) Collect, index, catalogue and provide storage for scientific and technical reports obtained from military departments; contractors of the military departments; non-military domestic sources; and foreign sources.

(*ii*) Prepare and distribute digests and abstracts of scientific and technical reports in order to acquaint the military departments and contractors with the information which was available.

(*iii*) Furnish bibliographical lists as requested.

(*iv*) Provide adequate distribution of scientific and technical reports and other documents to the Department of Defence and its contractors on either a loan or retention basis.

(*v*) Furnish similar and related services as required in the interest of efficient and economical dissemination of scientific information and utilisation of scientific documents.

The Director of Astia, Mr. Leslie Neville, was still engaged in planning its organisation. But already some of the points raised by Mr. Hall had been met, namely (1) it had established a common indexing code, (2) catalogue cards of a standard form were issued with most of the various Government reports, (3) it was a receiving and holding agency for all reports, whether American or foreign, and (4) it was one organisation to which all requests for information could be addressed.

He did not advocate the immediate setting up in the United Kingdom of an organisation equivalent to Astia because, for a variety of reasons, it was probably more than they could tackle. Further, it would mean a number of very high level decisions that were unlikely to be taken in the present circumstances.

However, all planning should bear in mind that it might be possible and desirable in the future to set up an organisation such as Astia, and it would be wise to remember that Astia existed. Meanwhile, it was essential that the most efficient use should be made of existing facilities, and it was for that

purpose that the Aslib Aeronautical Group had been formed. There were a number of problems which the Group could tackle, and at present it had three working parties. The first was compiling a union list of periodical holdings and intended to arrange for an inter-loan scheme among its members that would supplement the loan schemes of such organisations as the Science Library. Then there was a group considering the question of an abstract journal; there were a number of sides to that problem, not the least important being the question of cost; but from the report to be presented in April it should be possible to draw some definite conclusion. The third group was considering a scheme for the indexing of aerodynamic data.

Other immediate problems that could be considered were such things as a union list of report series, the question of a common index code and whether it would be economically desirable to issue catalogue cards with all reports.

There were many things which the Group could not do. A major problem for all aeronautical librarians was that of security; but although the Group might have recommendations to make, there was little that it could do effectively. Another problem with which it was concerned, but with which it was not certain how to deal, was the education of the aeronautical engineer in information matters.

Anyone engaged in design or research work must be more efficient if he were fully conversant with the various sources of information. There was no doubt, however, that many in the Industry were ignorant in that respect. The Group had in hand the preparation of a complete index to sources of aeronautical information which would be of value to all seriously concerned in the work, and was also considering the possibility of compiling a short booklet which could be issued more widely and which, possibly, would be of particular value to persons entering the Industry.

The Group believed in the importance of efficient information services, and felt that it had an important part to play in aeronautical development. The failures in information work tended to be more spectacular than the successes, for the failure to find a particular report might result in continuing uneconomic research work, costing much money. Yet the lessons of those failures, though costly, were learned slowly. The situation could be remedied by spreading the interest shown by those who attended the meeting that evening.

Professor A. D. Baxter (College of Aeronautics, *Fellow*): The emphasis in the discussion was on the two words "availability" and "use" of aeronautical information. He would dwell mainly on the word "availability," involving the classifying or indexing of information, for the whole problem was to make information available in the right form and in the right place. After that, its use by the individual was something they could not control.

The availability of scientific and technical information throughout the aeronautical world was rather mixed. It was like so many other things; in some directions there was a surfeit of material and in others a great dearth, indeed, such a dearth that he believed large sections of the Industry were almost starved for up-to-date information. That starvation meant greatly increased cost to the people concerned, for it was obvious that it resulted in unnecessary experiment and perhaps the inhibition of ideas which might have grown with the aid of a little information.

He had been fortunate in having first class libraries and technical information bureaux always on his doorstep, so that perhaps he could not appreciate fully what that dearth of information meant to some of the less fortunate.

On the other hand, while he knew the information was there, the very richness of it was almost an embarrassment in some respects. Therefore, he suggested a possible re-organisation in order that the embarrassment might be lessened. No one who was engaged in any particular branch of the aeronautical field had the time to study all the reports, even in his own specialised field, let alone the neighbouring fields. That difficulty was overcome by the issue of abstracts, accession lists and data sheets. But sometimes it seemed that librarians became a little over-enthusiastic and circulated all sorts of additional lists of information they might have received from other libraries. Frequently those lists were to some extent repetitions of the lists one received anyhow, but often one was afraid to ignore them, for by so doing there was great risk of losing useful information.

That co-operation between librarians and their enthusiasm for handing out lists was a

good thing; but why should the man who was seeking information suffer as the result of it?

Therefore, he advocated some form of centralised information service in order to overcome the trouble, but it need not be a large organisation. In the past they had had co-operative research in Industry, and he did not see why they should not have co-operative information services also. He believed that Aslib had taken the lead, and he felt that the Industry itself should now take a hand, for he was sure that it would derive great benefit therefrom, at little expense. His suggestion was that existing information bureaux should continue to supply data within their own requirements and limitations and to the demands of their special customers; but all of that, or certain parts, by agreement, could be passed to some central office which could issue a single comprehensive accession list or list of data, thereby avoiding duplication. Then one could be certain that the one list contained all the titles of the information available; if details were required, of course, one must go further.

The users of that method, in his view, would lose nothing, and some people would gain considerably. Quite an economy of effort could be effected if the librarians shared the work of reviewing books and articles, instead of all of them reviewing the same articles. The abstracts from one library would be sent to the central office, which would collect them regularly and make them available to the other libraries or bureaux; the central office would act largely as a co-ordinator and as a collecting office for arranging exchanges and loans.

As had been emphasised, time was an important factor. He believed such a central office could do the work very quickly; it would have to work largely on the telephone.

C. G. W. Ebbutt (Assistant Designer, Heston Aircraft Co. Ltd., *Assoc. Fellow*): He spoke from the point of view of the "user" in the practical field, particularly in relation to the small design department.

A small office could not carry a trained librarian as such, since the overheads became disproportionately loaded. That meant that somebody already occupied on design work must, as a part-time job, see to the proper analysing of technical matter which flowed into the library in ever-increasing quantity. A clerk could deal with routine registration and filing.

He was well aware that the best index possible was the personal notebook of the technical specialist. That specialist might be only too willing to help, but he also had some work to do, so that it was as well not to use that device except in dire emergency.

That raised the problem of classified reports. About 95 per cent. of the reports of any real use now were of a secret nature, and would not appear in a general index. After much experiment he had introduced in his organisation a coding system for tracing useful scraps of information buried in reports and other publications. The code used was restricted to eight digits, in order that it could be applied to mechanical sorting machines, often available in aircraft firms. That had involved some difficulties, but they had not proved as awkward as expected. The reports, when coded, were indexed on punched cards, which were clipped out according to the coding; those cards were on the Cope-Chat system. They could be sorted by pushing a knitting needle through the hole recording the coded information, and the cards giving reference to reports containing such matter dropped out. The complete system had been set down in a report circulated to interested parties by the Society of British Aircraft Constructors.

Having adopted the N.A.C.A. system in general, he understood that that august body had altered the code! The new code was not yet known, so that he did not know how much damage had been done.

At the Heston Aircraft Company they had been using the index scheme for the past 18 months and at the present time had about 3,500 reports coded and carded. Information could now be found readily, and very few searches occupied more than half an hour, whatever the subject, within aeronautical limits. The closer the required information was specified, the fewer cards were dropped. In a fair proportion of cases a single card was thrown up to complete the search.

His ambition was that a standard coding system should be adopted and that reports should be issued already coded by the issuing authority. That would cut out the whole of the hard labour by the firms. Needless to say, he hoped that something indistinguishable from his own scheme would be adopted!

The capital cost involved was small and, if reports were coded at source, the operating cost was negligible, since a good clerk, normally employed on other work, could cope satisfactorily with the routine of registration and the writing up and clipping of the cards.

It took about six minutes to sort the first digit or pair of digits through the whole pack of 3,500 cards. For the first pass the code number which would probably give the greatest number of rejections was chosen, so that on the next pass the number of cards to be handled was as small as possible. That was where experience paid big dividends.

The Zator Company in America had been working along similar lines. Presumably all genuine librarians knew all about it, but he was unaware of it until recently. The interesting point was that they had made full use of mutual interference in the coding of the cards.

The whole purpose was to get aircraft into the air, and they would fail in that purpose if, in the course of their deliberations, they did anything which caused delay or which did not help to achieve that purpose, or which brought the librarian side of the business so far into the light that the effort of getting the aircraft into the air became submerged in a super-organised system. There must be a happy medium.

R. L. Lickley (Chief Engineer, Fairey Aviation Co., *Fellow*): He spoke as one who had been partly at the producing end in the matter of reports and was now at the using end. The major problem was contained in the word "availability," involving, as the Chairman had put it, keeping people up-to-date. They could not separate those two items, and he suggested that "availability" started with the knowledge of what existed. If the potential users of information did not know of its existence, then the library or system which should deal with the matter was failing in its main task.

In general, the users consisted of two different classes of people, both equally important. The first group comprised students and teachers, and the second research workers and designers. He made a point of those two groups specifically because it led him to the question of security.

They all appreciated that security was necessary, particularly in a field which was developing as fast as aeronautics. But security could be taken too far and he was certain that at present the standard method of classifying reports, when there was any doubt, was to put them into the higher security class. At the College of Aeronautics they had had clear evidence of that on many occasions, and in fact abstract theoretical works on structures were often classified as "restricted"; but as soon as any question was raised, the restriction was altered to "unclassified." That matter should always be kept very much in mind. There should be maximum availability, and when there was any question as to classification, so long as national security was not involved, a document should be put into a class where it would be made available to the maximum number of people and not merely to a restricted number.

The means of telling people what existed could be, first, a plain list containing only a statement that the works listed did exist; or it could be a set of limited abstracts which did little more than amplify the titles; or, finally, it could go further and use the method of the "Index Aeronauticus," giving quite a lot of information about a limited number of subjects.

The abstracts, such as they were, must be available quickly. When he considered abstracts which had been useful to him and to others, he thought of the abstracts of the Institute of Aeronautical Sciences, published in their monthly *Journal*, and of those published by the British Non-Ferrous Metals Research Association, which, although not aeronautical, had always impressed him as being the outcome of an excellent system. What was needed in this country was a rapid means of producing something along the lines of one or other of those groups of abstracts. He emphasised the word "rapid," because, although there was difficulty in finding information on many subjects, most people had some means or another of finding it eventually. The important factor for availability was to let people know as soon as possible what new material had been issued.

The second factor in availability was the obtaining of the reports. There was a tendency on the part of librarians, having obtained a report, to keep it in their own organisations and to raise the utmost difficulty about releasing it. He exempted Mr. Cleverdon from that, but suggested that even

he had found that problem elsewhere. That was something which made it difficult for firms to know of information that had come from America to the various Government groups in London. The situation was improving, but at one period it was easier to get information direct from America than to try to obtain it through the usual sources here.

An organisation which was set up must tackle the problem of getting information to the people who needed it. He did not think it mattered a lot whether a particular report was in Manchester, Glasgow or London; if it were known to be available, a delay of a day, or even a week, was not important. The real delay occurred when one did not know that it was available and might spend weeks trying to find out.

They had tended to forget books. The number of books produced each month, of technical interest, which might or might not be directly related to aeronautics was tremendous; there was difficulty in knowing that American books had arrived or what was in them, and there was difficulty in getting them. Individual firms and libraries could not afford to buy every book. Hence there was need for a system which would give the library holdings, the places at which particular books could be found. The Royal Aeronautical Society gave very clearly each month a list of the books it held, and he suggested that that system could well be extended to cover the holdings of other main Institutions; in particular, if it were possible for the Science Library holdings to be made more public, that would be of great advantage.

He suggested that abstracting from magazines was going too far.

G. S. Henson (Vickers-Armstrongs, Supermarines, *Student*): He used, rather than supplied, technical information.

During the solution of complex aircraft design problems, the necessary processes of thought could be divided conveniently into four phases: investigation, incubation, inspiration and verification.

For example, a structural problem, the detailed solution of which lay outside the experience of the firm. During the investigation and verification stages they turned mainly to the library. For the purpose of discussion it was assumed that there was one over-riding problem in the structure being considered, and this could be stated as "What was the stress distribution about a large cut-out in a cylinder loaded by shear?" This led to a request for information under the subject headings of Cut-out, Cylinder and Shear. Finding such information usually called for many hours work, sorting through subject indexes, which might give two reports. Further detailed study of the reports might reduce this to one.

To cut short what was stated often to be a long story, one finished by roughly scheming structure by eye, and verifying that this was satisfactory by one theory which required more time for its solution than the whole problem was worth, considering the complete design. To avoid all this one tended to insert "what did not break last time"—at some unknown weight penalty.

From this example it was hoped that the following points were clear. A good subject index should be available and lead rapidly to the relevant reports within the library, and available elsewhere. The abstract or summary should give a fair amount of detail, including the time required to apply any theoretical methods presented. The latter point was important since it indicated the usefulness of the method; general investigations, tests, and crude theories were useful during the investigation stage, while considerable computational labour could only be undertaken during verification.

He favoured a punched card system for a subject index, such as that mentioned by Mr. Ebbutt, but working as far as possible within the Universal Decimal System. In his firm each useful item within the library was being given a card. The cards were first sorted on a colour basis into Structures, Thermodynamics, Aircraft Stability and Control, and so on. Each card was then punched under such headings (for structures) as shear, bending, end load . . . or cylinder, box, panel . . . or cut-out, diffusion . . . and so on. The application of this system to the example he had given was obvious. It would simplify the indexing process if title, author, abstract, rating and subjects could be published in any new abstracting journal so that it could be cut out and stuck directly on the punched cards. This would be an automatic process which could be done by a clerk.

Much of the information from the United States concerned *ad hoc* work and its value reduced with time. The supply of this

information had speeded up in the past few months, and while congratulating those concerned, he urged that further improvements should be attempted. There seemed to be little structural work coming from the United States; was this because comparatively little structural work was being done there, or because few structural engineers were serving on Selecting Committees?

There was also a lack of structural information about research aircraft; usually only the aerodynamic information was published. It should be possible, however, for the lessons learned in the construction of unconventional aircraft to be thought out and published. He appreciated that it was idealistic to ask that the lessons learned by the mistakes of the various firms should be published—for that was really what it came to—but he urged that if they could agree on the principle, they might find a way of doing it.

There often seemed to be an almost unhealthy rivalry between firms about the exchange of information. It had been said that at a recent course on swept-back wing structures, the representatives of various firms were afraid to ask questions lest they might show how much they knew. He thought that some rivalry was healthy but was that the present state?

J. A. Kirk (Short Bros. and Harland Ltd.): There were two main aspects of the problem of availability. The first was whether or not the required information existed, and if not, why not? That aspect was wide enough to form the basis of a separate lecture. Briefly, the main difficulties were the lack of money and of facilities or equipment which could be a consequence also of the lack of money, but it might be due to the inefficient use of the money provided. It was clear that the wealth of aeronautical data in the United States, compared with that available here, was a direct function of the testing facilities available, and had little or no connection with the scientists employed in the two countries. In the United States they were less worried by considerations of costs or manpower, and therefore they were able to do far more testing than could be done in Great Britain.

A third difficulty was the failure to report the information available. That again could be caused by money troubles, but its causes were more generally anti-social, however unconsciously. A large number of people kept information within their own works; they would make a detailed research on a certain item, but when they had gathered and digested the information they had obtained they closed the book: if they could be induced to write down their findings and publish them in report form, they would help others and would also help themselves. Unfortunately, at present many people tended to trust to memory.

A fourth difficulty was the failure to circulate the information available. Far too often, even if the information obtained were duly recorded, it was not given sufficiently wide circulation to be as useful as it could be. After a short time it might be forgotten altogether, and might just as well not have been recorded.

The second main aspect of the problem arose when information was known to exist and someone wanted to fish it out. He used the term "fish" deliberately, because most well known methods of filing information were reminiscent of the gentle art of fishing, and often required even more patience.

Some librarians used what was perhaps the most simple of filing systems, *i.e.* filing by report numbers; but if the librarian were not given the exact report number, he would not be able to locate the right report.

The next stage in the filing system was perhaps the author index system. That was based on the fact that an individual was usually employed throughout his life in the same field of work, and it was a workable system only because the literary output of aeronautical engineers was fortunately limited, and usually little time was required to obtain a particular report by scanning through the total output of one man.

Unfortunately, there were too many persons who were called Brown, Smith or Jones, and one of their purposes in life seemed to be to break down that neat filing system!

Librarians had a great number of filing systems, depending on the infinite number of subjects, using any number of systems such as the U.D.C., the N.A.C.A., S.A.I.S. and other lesser known filing systems; but few had really tried to use an overlapping system which was set inclusive instead of the usually mutually exclusive system, so that they could select information quickly. In fact that had given rise to the numerous filing systems existing, and the various

refinements used were a direct function of the number of cards to be rejected per search. The problem usually boiled down to one of economics; the smaller the number of rejects required, the greater the cost, and each librarian had to adjust his system within his monetary grant. Unfortunately, the time spent by specialists looking for the information required was seldom booked to the library cost and the true financial picture never came to light; otherwise it would be obvious to everyone that an apparently expensive librarian saved money.

The requirements to ensure making the maximum use of the aeronautical information available could be summed up as follows:—

(*i*) All the aeronautical information obtained by individuals, firms, universities, research establishments or other interested bodies should be properly recorded in a permanent form. That would include all tests, investigations, correlation of material and general analyses.

(*ii*) All reports should be given the widest possible circulation with due regard to the security side, which, unfortunately, was only too necessary these days.

(*iii*) Reports should be properly indexed and filed using a generally agreed filing system so that they could be extracted with the minimum amount of labour. To do that the selected indexing system should give a detailed description of all the information recorded in the report, together with the limiting conditions of the test or theoretical analysis, whichever was the case.

They should try to devise a filing system, flexible enough to be adapted to the various needs which everybody could accept. Obviously the needs of a small firm were not the same as those of the Royal Aircraft Establishment and other large establishments.

(*iv*) The training of librarians had also to be considered. He did not mean that the present-day librarians were not trained, but that he would like to see greater facilities offered so that librarians could be of maximum use to the research worker. For that reason, small firms should not hesitate to loan some of their specialists, even for long periods, to their library so that the librarian could make full use of their specialist knowledge to form the foundation of an efficient library service which would soon repay its cost Was it not a fact that tests or special investigations were repeated over and over again because the report containing the precise information required could not be found or located?

Contributed: In his introduction, the Chairman rightly stated that the foreign information should be taken into account.

Because most of the foreign publications were written in languages other than English, they were seldom consulted by English speaking engineers and research workers and, although the output of the foreign reports was only a fraction of those published in America and in Great Britain, many important developments never had the publicity they would have had they been printed in English.

He would like to make a plea for an internationally agreed system of aeronautical annotation as, if aeronautical writers all over the world used the same annotation, the figures and graphs of the various reports could be easily understood without the need of translation (after all, a mathematical formula could be understood in most languages); if the figures and graphs of foreign reports could be assimilated easily, one could easily decide whether the text was worth translating or not, for the purpose of the work undertaken, and the load of the translators would thereby be reduced enabling them to concentrate on the more useful translations.

It was interesting to see that, at least in elementary aerodynamics, most people now used the same variables and only the initials or symbols were different: for example, lift coefficient was known generally as $\text{LIFT}/\frac{1}{2}\rho V^2$, but unfortunately it was called C_L, C_a and C_z in the English, German and French languages respectively. This also applied to most of the other abbreviations of symbols with the result that it was difficult to understand and translate mentally the meaning of figures and graphs given in foreign reports. The final result of all this was that foreign reports were not usually consulted, even if they were available, and valuable information was lost, giving rise to more duplication of the experimental and theoretical work.

It would appear that there was a case for an agreed system of aeronautical annotation acceptable to all, as it would lead to a greater use of the aeronautical information existing in all countries.

B. D. Jones (*Assoc. Fellow*): As a user of libraries, he discussed the problem of the means of circulating information from its source to those who needed it. One source was the individual in a firm. Often he had to engage in some sort of minor research in his own right, build up a body of knowledge from published information, put it into a form in which he could apply it, take notes of it, draw curves, and so on. But when he had finished with that knowledge it went into his firm's file or into his own private notebook. It was available to his immediate colleagues who knew he had done the work, but not even to other sections within the firm; certainly it was not available to other firms. That meant a waste of applied science.

Again, it was most unusual that a firm's data ever got out of the firm. There was one case, however, where the Bristol Aeroplane Company had written a text book for its own use and the Ministry had published it for general use; that should be done as a general rule, not only in wartime.

Published data was not in a form suitable for circulation to engineers; an anonymous example was that of a senior draughtsman who had a special job to do, and, having a good librarian, had accumulated twelve reports covering the ground all around his problem, but could not put them together to form a clear picture. He went to a draughtsman, a stressman and an aerodynamicist, but they could not see as a group what it was all about. After some weeks the firm had called in a specialist, who had told them what to do. Surely the proper course was for the specialist to write up the twelve reports, which were clear in his mind, to give a picture of the whole affair.

Libraries were good in parts. If a known reference were taken to a library, in however scrappy a form, they would find what was wanted. But if a general request were made for information on an unusual subject, the library staff would normally be unable to supply it. He quoted an investigation carried out by D.S.I.R. Intelligence "Unanswered Questions, No. 5." A junior was set a list of known references for which to obtain abstracts; he got abstracts for 84 per cent. of the references. Then a senior person in the office was set to find references on that subject, and found less than half the known references. Another senior repeated the investigation and also obtained less than half the known references. The point was that the subject index was not good enough.

In that connection there was a recent paper entitled "The Well-Tempered Aircraft"; how would that be indexed? In his view it would be necessary to go right through the paper and to catalogue it into half a dozen or even a dozen items. Another recent paper with which he had to deal (TN 2094) was indexed by N.A.C.A. under "aluminium," "material properties—tensile," "material properties—compressive," and under the name of the author—"Miller, James A." Instead, the paper should have been indexed under the particular aluminium alloy, 24S-T86 Alclad, and under stress-strain curves, stress-deviation graphs, and elongation as a function of gauge length.

The particular property he had wanted was the variation of elongation with length. A subject index in detail was required.

In order to provide an adequate detailed subject index, the librarian should have "on tap" a number of experts. They should not be in his department, but should be his colleagues who, being bothered by the lack of a good subject index, would be prepared to give their spare time to improve it.

He had suggested that when librarians were asked for sources on unusual information, it was found normally that they were floored. Obviously that was because they were not trained as specialists in all branches of aeronautical technology; what was more, they should not be so trained, for they should be able to go from a municipal, to an aeronautical, and then to a biological library. It was not possible for librarians to be trained in all branches of aeronautics—structures, aerodynamics, engines, hydraulics, electrics, radio, metallurgy, air transport, repairs and maintenance, etc. It was for the librarian to provide the information, not necessarily to understand it. Therefore the librarian should have the assistance of experts who were prepared to supply references and to answer awkward questions. The librarian would have to take it on trust that they were experts; but whenever he received a request for information he should submit that request to two of his experts, so that there would be a cross check.

G. F. Webb (British European Airways, *Assoc. Fellow**): He was an amateur whose

* As Mr. Webb was unable to be present, his contribution was read by Mr. R. C. Wright, also of B.E.A.

study of the means of access to data had been necessitated by a lack of any generally-accepted method or training facilities.

Of the four main headings into which the subject might be divided — LOCATION, SELECTION, COLLATION and DISSEMINATION —it appeared that the LOCATION of material was the simplest. SELECTION necessitated specialised knowledge, in addition to a broad outlook in relation to the field covered; it also required the ruthless elimination of sub-standard material, an operation often insufficiently practised.

By COLLATING or assimilating data into a system of classification it was possible (*a*) to relate similar items, (*b*) to separate dissimilar items and (*c*) to be able subsequently to find things. For general use, such a system should be:—

(*i*) Simple, to encourage its practise by all concerned as part of their daily life, and to ensure that isolated subjects were easily accommodated.

(*ii*) Capable of infinite expansion with minimum time and trouble.

(*iii*) Universal: It was impossible to prevent the overlapping of any number of subjects, and the restriction of subjects was difficult.

(*iv*) Existing and proven: Technical users had no time to consider the system, which must be a tool and not a master.

(*v*) Accessible, to overcome the users' natural inertia.

Regarding DISSEMINATION, it was important that potential users were made aware of all means of assistance available to them in obtaining data.

It was essential to take the system to the user wherever possible; but successful dissemination must depend ultimately upon the education of the user to accept it. Then, as the inevitable specialisation of interest developed, the fundamentals would be less easily overlooked.

Much confusion in the early stages of higher education could be avoided if specialised subjects were constantly related to fundamentals by means of methodical classification. The main difficulty in introducing that might lie in converting the teachers!

An appalling indifference was apparent in the average engineer towards the systematic use of data (for example, how often was the Index to the JOURNAL mislaid?). For him to neglect the minor obligations incurred by the use of available facilities was all too common. That state of affairs undoubtedly resulted from a gap in training. Its consequence was a waste of time and manpower, which could largely be avoided by the orderly arrangement of data to ensure its accessibility.

For this purpose the Universal Decimal System (British Standard 1000) seemed to offer advantages over several other accepted methods of classification. No existing method was perfect, but it was disappointing that, although such a convenient and adaptable system was so easily available, some authorities seemed content still to await perfection. Certainly the technician's rapidly expanding needs would become increasingly difficult to satisfy by existing means.

Apart from the potential value of U.D.C. in other fields, students in particular could summarise the Index to B.S.1000A on cards to produce a cheap and useful quick-reference framework for technical and personal data, suitable for subsequent expansion in any desired subject and extent. It seemed that the educationalists could give valuable guidance to students by the encouragement of such a method at an early stage, and by the provision of facilities for its habitual use.

J. W. Griffiths (Vickers-Armstrongs Ltd., Supermarines, *Assoc. Fellow*): From his experience in an aerodynamics section, he thought that the problem of making technical information available could be divided into two parts. First there was the aspect with which librarians were mainly concerned; that of making sure that they could find data which was required on any subject if it were available anywhere. He had every sympathy with any efforts made to find a universal indexing system, so that when a librarian was asked for information on a particular subject he could state if it existed, and produce it without much delay.

The other aspect of the problem was a greater source of day-to-day worry to the "users" in an aerodynamics section. There were some subjects which arose every day or even every week, on which there was a large amount of data available. The problem was to select that which was reliable, authoritative and, where progress of the subject was rapid, up-to-date, without spending a disproportionate time indexing. His

problem might be made clearer by describing the system used in his own section when a new report was received. They had a punched card index system with which any required information might be found immediately under an explicit heading—or set of cross-referenced headings—and he thought that system was preferable for day-to-day use to a coded system. The new report was indexed on a card under the appropriate subject headings, and in addition each card had three "quality" headings. The first heading indicated that they knew nothing about the report beyond its existence; the second that someone in the section had made good use of it, and the third that it was recommended, and was an authoritative or staple report.

It was difficult for any authority who might be preparing a monthly digest (and he assumed they had agreed that that was desirable) to state just what they thought of a report, because the statement might get back to the author and could lead to trouble. But he suggested that some system of indicating the merit of a report might be worked out by the authority, for example R.A.E., who were preparing the digest. In the first category came a summary of the contents of a report. In addition it was stated whether any use had been made of the Report at R.A.E., for example that it was quoted as a reference in some report in course of issue by R.A.E., or for some other purpose, with a third category for those reports which had the R.A.E.'s whole-hearted recommendation.

Dr. D. Küchemann (Royal Aircraft Establishment): He spoke from the point of view of the ordinary research worker. Assuming that a good library and filing system was available and that full records existed, how was he to know about them? If he embarked on a new subject he was perfectly willing to spend some time and effort in learning the filing system so that he could find the information he wanted. But on his own subject he also wanted to keep up-to-date, and his problem was how to do that, how he was to know of incoming reports. The lists being circulated at present were not complete, and the same paper might turn up in various lists under one or two N.A.C.A. numbers, by a T.I.B. number and again by an A.R.C. number. Confronted with the knowledge that a large number of reports was issued from various sources, and being unable to spend the time consulting existing lists and card indexes, he had the uncomfortable feeling that he was missing quite a lot of information which might have been of value to him in his work.

He felt that the situation could be improved quite simply. Considering first the reports that were distributed in mimeographed form, he would be quite satisfied if there were a monthly or quarterly distribution of abstracts, each of about 100 words. Even if they were not very good, they would give some idea of what was in the reports. The subdivision of the lists need not be very detailed; a subdivision following the departments of the R.A.E., for example, would be quite sufficient. What mattered more was completeness. The abstracts should cover not only everything issued by the various research establishments and universities in Great Britain, but also all that could be obtained from outside the country. Then a detailed index once a year was likely to satisfy most people.

The position with unclassified papers which were published in printed periodicals appeared to him to be utterly confusing, and he found it impossible to keep up with the information available. His chief source of information remained the *Journal of the Aeronautical Sciences* and possibly one of the American abstracts, apart from one or two quarterlies. But what happened in the countries of Europe, for instance, escaped him altogether. There must be something available; but who had the time to spend hours in the library to find out? What was urgently needed, therefore, was a European journal on the same level as the *Journal of the Aeronautical Sciences* in the United States, contributed to by all European countries having interests in aeronautics.

They might be able to go a step farther than the American journal by expanding the section called "Reader's Forum" into a collection of abstracts to which the authors themselves would contribute short summaries of papers which were published elsewhere. Main articles should also be as short as possible, and considerable space should be given only to papers of real importance which summarised notable developments. The latter, preferably, should be commissioned by the editors. The new journal would not supersede existing journals and combine them into one, but would represent a common forum for all of them. The large area from

which contributors could be drawn should ensure that the papers were of the highest level, which, in turn, should prove very stimulating.

He was prepared for many arguments against such a plan, from those calling it unrealistic and impractical, to those pointing to the language difficulty. The language difficulty however was not so very serious for everybody; and the proposed journal could well be printed in several languages, such as English, German, French and Italian. To be neutral, it might be called "Acta Aeronautica." It could not be denied that the present state of affairs was unsatisfactory.

Through the columns of such a journal they might meet a great many people who were working in the same fields of aeronautics as themselves, and they might then make use of the fact that some people remembered a paper more easily by its author than by its number, thus mobilising the human element where the card index failed.

In the establishment of the European "Acta Aeronautica" Great Britain had a fine opportunity for taking the initiative.

J. W. Lane: He was engaged in the patents profession. In a letter published recently in *Flight* the writer had wanted some information, which the publishers of *Flight* were not able to supply, about a particular system of aircraft propulsion. It appeared that, about the year 1911, a correspondent in the United States had written to the inventor asking for information about the system, but the inventor had not supplied it. It was covered, however, in one of the first patents to be taken out appertaining to a form of turbo-jet propulsion for aeroplanes; here was a source of information—Patents—which should not be forgotten.

From the discussion it seemed that there was a great need for a central bureau of aeronautical information. The drawback in Industry, he believed, was not so much one of finance, but rather of design and other departments staff finding the time required to write reports on their work and research. Therefore, too much reliance should not be placed on technicians in the Industry to produce reports themselves; rather should there be suitable qualified mobile specialists from a central bureau who would visit the various firms in order to report on the progress and findings resulting from research work in the Aircraft Industry, in so far as security conditions permitted.

He agreed that the staff of such a central organisation should be not only librarians, but technicians, because aeronautical science was a deeply involved subject. In view of the fact that to-day one research worker did not know what the next one was doing, except with regard to basic principles, they could hardly expect a librarian who had had a general training only to be able to assimilate information of a highly technical character quickly.

R. G. Thorne (Chairman, Aslib Aeronautical Group, *Assoc. Fellow*): It was important, if they were to develop information services in the Industry, that they should foster the interests of the user in all aspects of information work. There was no doubt that some of the users were deeply interested, and he looked forward to the day when it would be natural to assume that the scientist and the technician were fully aware of the information problems that existed and of the facilities available. During the discussion some interesting and pertinent points had been made which had indicated that some of the speakers did not know of the existence of facilities to meet their needs. (He would deal with these points in detail in a written communication.)

There were two broad requirements which had arisen from the meeting. First there was obviously a need for a published aeronautical abstracting journal, and secondly for an educational programme for both aeronautical librarians and information officers; and also for technicians and scientists.

He thanked the Society for giving an opportunity for airing the problems that existed.

W. S. Hollyhock (*Assoc. Fellow*) *contributed*: There was much comment about details of coding and methods of handling information at the user end but, apart from one or two references to a central body, little that was constructive was said about the larger problem of improving the availability to the user in the general sense. He could not help feeling that the task of editing, collating and coding of the information (not solely aerodynamic) becoming available, was so formidable as to render it impossible for a single body to tackle it satisfactorily. Would it not be possible, therefore, for some

central body, such as the Department of Scientific and Industrial Research, Ministry of Supply, or the Society of British Aircraft Constructors, to arrange for collection of the information, and then pass it on for coding to a number of other, more specialist, bodies? If some half dozen or so universities or similar bodies could each be prevailed upon to handle a certain aspect of the job, its magnitude would be reduced to more reasonable proportions. For example, one university might take on the task of translating from the German, another the Italian. These would then pass the translated information to the specialist centres dealing with the particular branches of knowledge concerned, *e.g.* structures, aerodynamics, etc. The latter would deal with this information and also that which, because it was in English, they would receive direct from the central body.

The central body would make available to the users the names of the various bodies dealing with the various types of information and would then leave it to the user to approach the particular body when requiring information of a specific nature.

The main financial burden, which obviously could not be borne by any private body, would then fall on the Government or the S.B.A.C. The cost of coding, and so on, at the specialist centres presumably would be shared by the Industry and the Government, or covered in some other manner which would not place too heavy a burden on any one section.

It would be highly desirable, of course, that all the parties concerned used the same system of coding. This would allow individual users to classify within their own organisation such material as they obtained through private sources and that which they had from time to time obtained from the specialist bodies. This would ensure that further requirements would be satisfied with the minimum delay, as they could then be more precise in their requests to the specialist bodies in those cases where the information which they required bore any resemblance to any that they had previously obtained.

This suggestion was naturally somewhat sketchy, but he felt that it would be possible to work it up into a satisfactory system for dealing with a problem which was undoubtedly too great for any single body to carry out successfully on a reasonable financial basis. Furthermore, it would not require the full-time services of so many highly technical personnel as if the work were done by any single organisation—even if such a number of people could be brought together in one concern.

The Chairman (A. A. Hall): Mr. Thorne was right; it was obvious that some people were unaware of a number of the channels which were open to them in seeking information; one of the things which had come out of the discussion was the need to make the existence of those channels clearer to potential users. There was a certain amount of agreement on the need for some centralising activity.

He felt that the Royal Aeronautical Society might well come to the view that it had a part to play in the matter.

Cyril Clevedon (*contributed*): Several speakers spoke in disparaging terms of libraries and librarians. There was little doubt that as a class, aeronautical libraries in Great Britain were not as good as they should be. That was not necessarily the fault of the person who was nominally in charge, and was in no way a condemnation of libraries as such. Aeronautical libraries had fallen below the standard set by libraries in many other industries simply because those responsible for finance and policy had failed to realise their potential value. It was an example of the prevailing attitude that Mr. Ebbutt should say that his firm could not afford a librarian, and then that a designer must stop designing (for which he was presumably trained) and spend part of his time running the library. Equally so, when Mr. Kirk suggested that a librarian should have help from a specialist to advise on a filing system. There seemed to be a complete failure to realise that librarianship was a profession involving a great deal of training, that a qualified librarian was a specialist in filing systems and in all other matters pertaining to the running of a library.

There was obviously much confusion on the respective duties of a librarian and information officer. Basically the librarian was responsible for obtaining, indexing and filing all information that might be of use, whether it be contained in books, reports, periodicals, patents, drawings or correspondence. He must so arrange his system that he could supply on demand a specific report or, alternatively, supply all the

information contained in the organisation on a certain subject. It was only when this had been done that an information officer could carry out his work. His duties were concerned with seeing that information which came into the organisation was brought to the notice of those particularly concerned. This might be done by personal and individual attention, by abstract bulletins, bibliographies and other similar methods. It was obviously desirable that this person should be an aeronautical engineer, if he were to do his work to its fullest efficiency. In practice much of the work could be done on a routine basis by an intelligent librarian; it was not necessary to know all the equations of motion to find or supply information on the ideal drag of a shock wave or the effect of ram-jet pressure pulsations in supersonic diffuser performance. But it was essential to have a good subject index and without this even an aeronautical engineer would soon find himself in difficulties if he had to provide answers to the wide range of questions asked of a technical librarian. If Mr. Jones found that an unusual request generally floored a librarian, the fault was possibly with Mr. Jones, for of the four methods of identifying a report—date, author, source of origin, subject—it was most unusual for more than two to be correctly quoted. Normally the librarian was asked for an R.A.E. Report by Robinson published in 1949, whereas the enquirer actually wanted a N.A.C.A. Technical Note written by Robson in 1946.

Whereas an aeronautical library could function satisfactorily (albeit in a restricted way) without an information officer, it was impossible for an information officer to do his work unless he had the resources of a well-equipped library. Therefore it seemed obvious that whereas the trained librarian was essential, the information officer was a desirable but non-essential luxury.

Possibly the nearest to the ideal aeronautical information service in this country was that of the Royal Aircraft Establishment. Under the overall control of Mr. R. G. Thorne, there were professional librarians to organise and control the library side, while the information service had a general information officer working full-time in the Library, with information officers in each department, who divided the time between their department and the Library. Although at first this might seem to be an expensive organisation, in practice it was certain that the saving of time of the design and technical staffs was such that a large overall saving is effected. This would apply equally well in any aircraft firm in the country.

The present practice in many firms was that, when information was required, the person concerned visited Farnborough. Although such journeys might be essential sometimes, there were many occasions when they were a waste of money and, more important, of time; they could have been obviated by the provision of an efficient information service within the organisation.

R. G. Thorne (*contributed*): Punched cards and other sorting aids could be applied usefully in specialised areas, but what was urgently needed at present was an agreed classification system. The Ministry of Supply in general used the Universal Decimal Classification and although it required revision in the aeronautical areas, he would like to see it adopted by the Industry. There was evidence that the majority of Aeronautical libraries with a classified index used the U.D.C. Revisions of the Aerodynamic, Military Engineering and Radio Sections were in hand and he hoped it would be possible for a Working Party of the Aslib Group on the U.D.C., to start work in the near future. Once there was a common coding generally accepted by the Industry the way would be opened for substantial improvements in the information services available, by affording opportunities for improving the co-operation between the various libraries and information bureaux.

Mr. Ebbutt had described the application of Cope Chat cards in his organisation but it must be stressed that those mechanical aids were useless without a good coding system. The N.A.C.A. System was good for cataloguing aerodynamic wind tunnel tests but failed badly in the broader fields which must inevitably be covered by the Library of any aeronautical organisation. He would suggest that a system similar to Mr. Ebbutt's would be useful for coding in detail requests containing numerical data of interest to certain specialists, but he doubted its value for the average aeronautical library's index.

Mr. Henson had stressed the large amount of structural information tied up in the files of individual firms. Perhaps the S.B.A.C. and the Royal Aeronautical Society could get together and expand the scope of the Stressed Skin Data Sheets to include that information. With the present shortage of

skilled stressmen they needed a much more co-operative outlook by the Industry in this matter. Mr. Jones had also indicated the need for a wide expansion in the production of Data Sheets and they might look forward to the day when Reports included Draft Data Sheets for early criticism by the Industry.

It was obvious from the discussion that the Aeronautical Industry faced numerous problems based on the supply of aeronautical information. He believed that the Ministry of Supply, the S.B.A.C. and the Royal Aeronautical Society, co-operating together, could solve those problems, although it might take some time. In the Aeronautical field, Research was probably more closely tied to Industry than in any other field, but even so the time interval between the conception of a Research Index and its ultimate production was still too long. A deeper understanding of the value of libraries and information Bureaux by Management was essential if the lag between Research and Technological Advances were to be reduced. The Aslib Aeronautical Group was attempting to foster interest in the problems that existed and was attempting to find solutions, but it must be supported by the Industry as a whole.

*Fatigue of Aircraft Materials with Special Reference to Micro-Structure**

by

P. L. TEED, F.R.Ae.S.

INTRODUCTION

Of the many kinds of fatigue of materials, this paper deals only with "The fatigue of ductile metals by the imposition of cyclic stresses." It is the purpose of the paper to show that:—

(*i*) Metals have certain very human attributes.
(*ii*) They have both memory and temperament.
(*iii*) They remember with increasing resentment the stresses which have been imposed upon them.
(*iv*) They are extremely sensitive as to the appropriate moment at which to break.

MECHANISM OF FATIGUE

The question arises of why a piece of any ductile metal, other than a ferrous one, free from any abrupt change of section, when subjected to cyclic stresses of any magnitude, however small, ultimately breaks although the maximum stress imposed is one which, if static, it could have borne indefinitely. The answer is—mainly because of its metallographic structure. This gives rise to:—

(*a*) localised transitory plastic flow—generally by the sliding of one crystal plane over another,
(*b*) work hardening, and
(*c*) cracking, usually producing a fractured area, having brittle characteristics, and finally
(*d*) another type of cracking giving rise to a fractured area often showing ductile features.

METALLIC STRUCTURES

To illustrate the effect of metallographic structure, some examples of structures are shown and it is explained how, in the author's view, they give rise to the closely linked evils, localised plastic flow, work hardening and cracking.

All metals and alloys are made up of crystals and all crystals are made up of atoms, arranged in accordance with one of 14 different patterns or lattices. Fig. 1 shows a photo-micrograph of cast gold, taken at the Royal Mint. After refining, there is less than one part in 100,000 which is not gold.

In Fig. 1 (p. 429) a metallurgist can see allotriomorphic crystals and inter-crystalline boundaries. The word "allotriomorphic" is explained as follows. When crystallisation starts, the atoms take up their positions in orderly array according to the lattice to which they belong. The internal structure of each of the crystals is orderly, but the more vigorous encroach on the territory of the weaker, giving rise to boundaries in no degree suggesting those of crystals.

Something must now be said of both crystals and of their boundaries. With few exceptions metallic crystals are remarkably anisotropic as regards their elastic moduli.

ELASTIC ANISOTROPY OF METALS

Table I shows the ratio of maximum to minimum Young's modulus of single crystals of some common metals (note particularly gold).

Having established that metallic crystals are generally elastically anisotropic, something must be said as to the inter-crystalline boundaries. To quote Professor Orowan, "they can be likened to two-dimensional glass." In fact a polycrystalline aggregate can be regarded as a number of springs, in

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* Lecture read before the Bristol Branch of the Society on 2nd January 1952.

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random orientation, separated from each other by an infinitely thin film of a viscous plastic—these scientific or pseudo-scientific terms describe a common or garden piece of metal.

CRYSTALS AND THEIR BOUNDARIES

At temperatures well below the melting point of metal or alloy, it has long been established that the inter-crystalline boundary is stronger, but less ductile, than the crystals.

With this fact in mind, remembering the elastic anisotropy of the crystals, it will be appreciated that if a load is applied, even to a piece of pure metal, the stress pattern within it will have about the simplicity of a patchwork quilt, made up with patches prepared by tearing rather than cutting.

This very pure metal is, in some respects like a West of England stone wall, made of irregular lumps of laminated stone, of random orientation, joined together with cement stronger than the stones.

STRUCTURE OF ALLOYS

Turning now from pure gold to Duralumin (Fig. 2, p. 429) results at once in a field of greater complexity. Interspersed in the matrix are sizeable pieces of at least three inter-metallic compounds, $CuAl_2$, Mg_2Si and AlFeMnSi: all these look the same in monotone, but are readily distinguishable under the microscope. The elastic constants and ductility of these inter-metallics differ considerably from those of the matrix, a matter worthy of thought, considering the internal stress pattern of a piece of metal subjected to an internal force.

Other pictures might be shown of alloys containing more than one phase, such as common forging brass, which has an alpha and a beta phase. Since, in general, in such alloys, the physical characteristics of the two phases differ considerably, the application of an external load may produce a degree of complexity in stress distribution within the alloy much greater than that caused by the anisotropy of the crystals of some single-phase polycrystalline aggregate.

Turning to another stage in the build-up of the picture, there are, in engineering alloys, non-metallic constituents. These are due to the method of manufacture and their presence, although in some degree controllable, cannot be wholly eliminated. Two examples might be given; slag in wrought iron and manganese sulphide in steels. Further, intentional inhomogenities are commonly introduced to facilitate machining, such as

lead in steel and brass,
sulphur and phosphorus in steel,
lead, bismuth and antimony in aluminium alloys,
selenium and tellurium in copper alloys.

These are referred to again later.

TABLE I

RATIO OF MAXIMUM TO MINIMUM YOUNG'S MODULUS OF SOME SINGLE METALLIC CRYSTALS

Tungsten	1.0
Aluminium	1.2
Alpha iron	2.2
Silver	2.7
Gold	2.7
Copper	2.9

PRECIPITATION HARDENING

There are, as well, the inhomogenities arising from precipitation hardening, a metallurgical technique less than half a century old, yet now a commonplace of fabrication procedure. Two examples are given:—

(*i*) A wrought 2½ per cent. beryllium-copper alloy (Fig. 3, p. 429).

(*ii*) A cast magnesium-aluminium-zinc alloy, AZ 91 or D.T.D. 136B (Fig. 4, p. 429).

Besides the visible changes arising from precipitation hardening, micro-stresses are engendered, giving rise to increased distortion of the crystal lattice. This is referred to later.

In the upper portion of Fig. 3 the alloy is in the solution-treated condition. In the lower portion the same alloy is in the precipitated state and a new phase is visible.

The top portion of Fig. 4 shows the "as cast" structure, D.T.D. 136B or B.S. 1273; the middle portion is the same piece after solution heat treatment, D.T.D. 281A or B.S. 1274; the lower portion shows the effect of precipitation heat treatment, D.T.D. 285A or B.S. 1275.

COLD WORK

Another type of structure, that brought about by cold work, is now considered. The original gold specimen, after it has been cold rolled, shows a remarkable change in appearance (Fig. 5, p. 430). A laminar structure has been developed and, as a result of the cold-rolling, the metal is full of locked-up or residual stress.

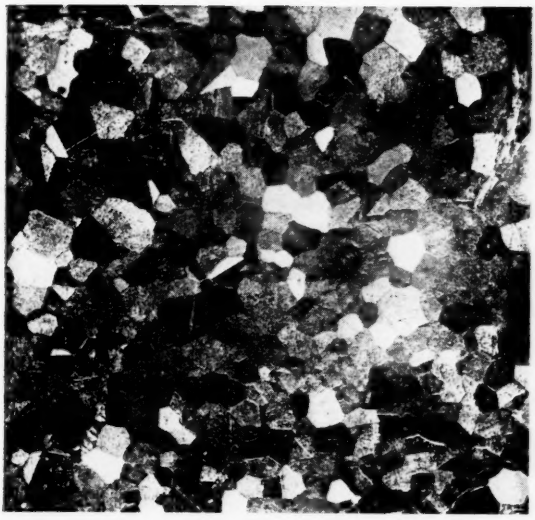


Fig. 1. Cast gold (magnification 3.2 diameters).

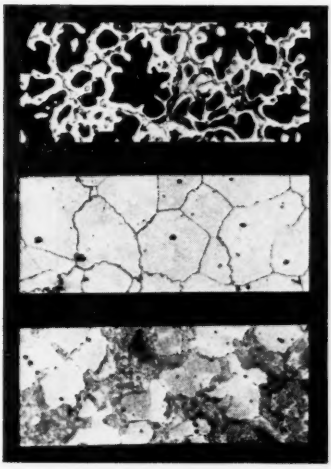


Fig. 4. Cast magnesium-aluminium-zinc alloy, A.Z.91 or D.T.D.136B (magnification 150 diameters).

Fig. 2. Duralumin (magnification 200 diameters).

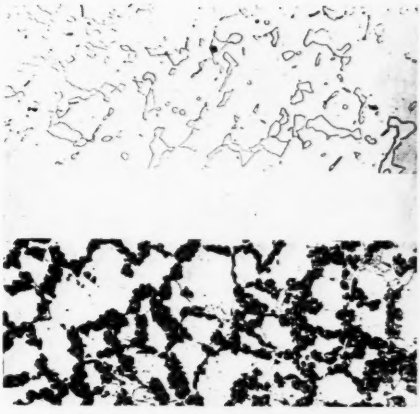


Fig. 3. Wrought beryllium-copper (magnification 50 diameters).

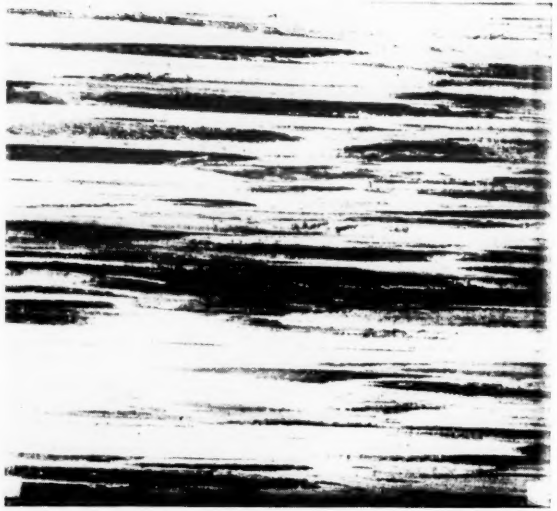


Fig. 5. Gold after cold-rolling (magnification 3 diameters).

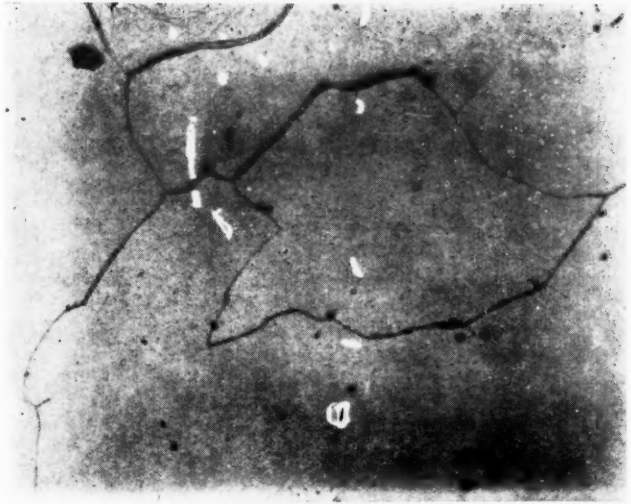


Fig. 7. Annealed Armco iron (magnification 1,400 diameters).

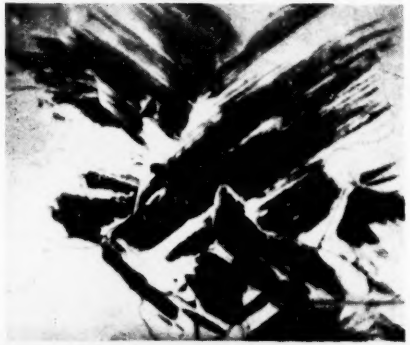


Fig. 8 *(Left)*. Annealed Armco iron after the application of cyclic stresses (magnification 1,400 diameters).

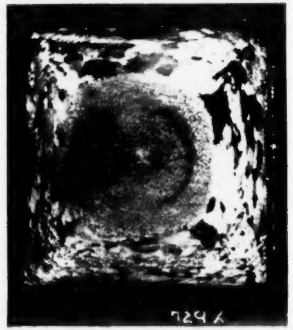


Fig. 12 *(Right)*. Variation in grain size, D.T.D.364 (about half scale).

Fig. 9 *(Left).* **Clad duralumin (magnification 500 diameters).**

Fig. 11 *(Right).* **Development of a complex system of cracks in a cyclicly stressed cantilever beam (magnification 100 diameters).**

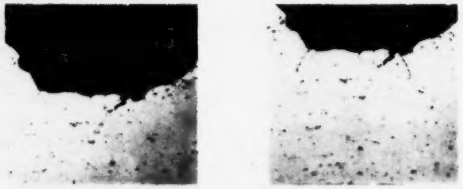


Fig. 10 *(Left).* **Development of a crack in duralumin (magnification 50 diameters).**

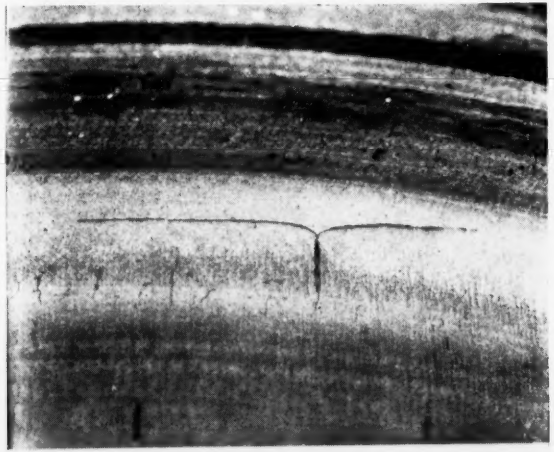
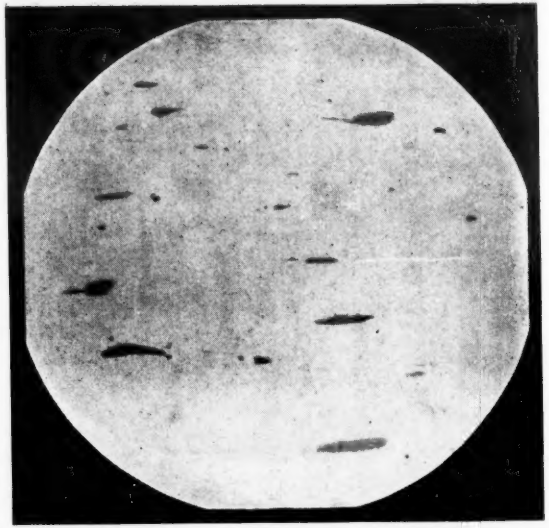
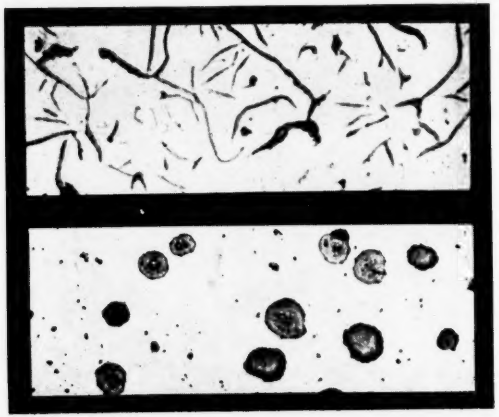


Fig. 16 *(Right).* **Section of a crankshaft which failed by fatigue (magnification 5 diameters).**





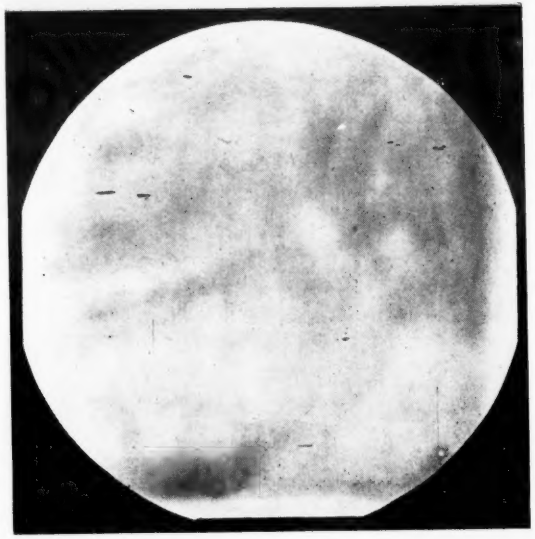


Fig. 17 *(Top Left)*. **A free-cutting mild steel (magnification 100 diameters).**

Fig. 18 *(Above)*. **A steel of approximately the same composition as Fig. 17 (magnification 100 diameters).**

Fig. 19 *(Left)*. **A hypo-eutectic cast iron (magnification 100 diameters).**

SUMMARY OF STRUCTURAL EXAMPLES

In trying to demonstrate the complexity rather than the simplicity of the fatigue problem, the following examples have been given:—

cast pure gold and cold-rolled pure gold,
Duralumin,
beryllium-copper in two conditions,
the cast magnesium - aluminium - zinc - manganese alloy in three conditions.

Many more could be shown, but these should give some idea of the complexity of the structure of a piece of metal.

THE NATURE OF ENGINEERING ALLOYS

To the metallurgists and increasingly to the engineer, although not to the pure mathematical physicist, alloys are generally composed of a heterogeneous conglomeration of of allotriomorphic crystals differing in size, orientation and chemical composition. They are probably interspersed with physical discontinuities varying from Griffith cracks, *i.e.* micro-cracks or smaller, to substantial cavities. They are likely to contain inclusions, such as oxides, nitrides, sulphides, and so on, of the metals of which they are composed and also inter-metallic compounds.

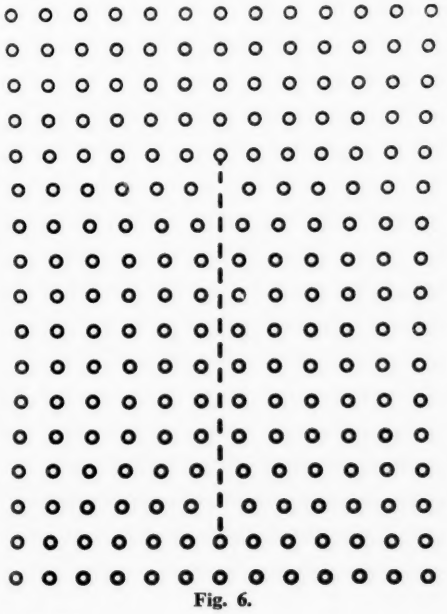


Fig. 6.

In addition, there may well be flux, slag, sand and strangely retained gases, and there will, of course, be boundaries between these chemical and physical entities, the physics of which is ill understood but is surely not without significance.

Superimposed on this there will probably be a random distribution of residual stresses arising possibly from heat treatment or cold work or both.

Because of these complexities and of their influence on stress distribution within a piece of metal, it seems obvious that the proper study of the fatigue problem involves the carrying out and interpretation of the results of realistic experiments rather than treatment on mathematical-physical grounds. This is the theme song of the experimentalist.

STRUCTURAL CHANGES CAUSED BY CYCLIC STRESSES

The author does not see metals as a largely ordered array of atoms, such as shown in Fig. 6, which was taken from a British paper on fatigue. In the centre are some atoms which are stated to have taken up wrong positions, although it is difficult to see how there can be any question of right or wrong in this matter.

The next two illustrations are realistic and historic for they illustrate the change in structure produced by cyclic stresses when applied to nearly pure iron. The photomicrographs were made by Gough and Hanson in 1923. The material in Fig. 7 (p. 430) is annealed Armco iron of high purity. Due to annealing, residual stresses would be almost absent and because of the purity of the metal, stress raisers are virtually absent. In fact, this is almost an ideal piece of metal. Fig. 8 (p. 430) shows the same specimen after the application of cyclic stresses. The stress reversals have been 40×10^6 at ± 12.2 tons/in.^{2} and the slip planes which have developed should be noted. The specimen would have withstood indefinitely cyclic stresses of the magnitude imposed but, had the peak stress been raised another $\frac{1}{2}$ ton/in.^{2}, the development of further slip planes would have produced such an incapacity for further plastic flow that a crack would have developed in one of the work-hardened grains and would have spread gradually across inter-crystalline boundaries to similar planes into suitable orientated crystals until complete fracture took place.

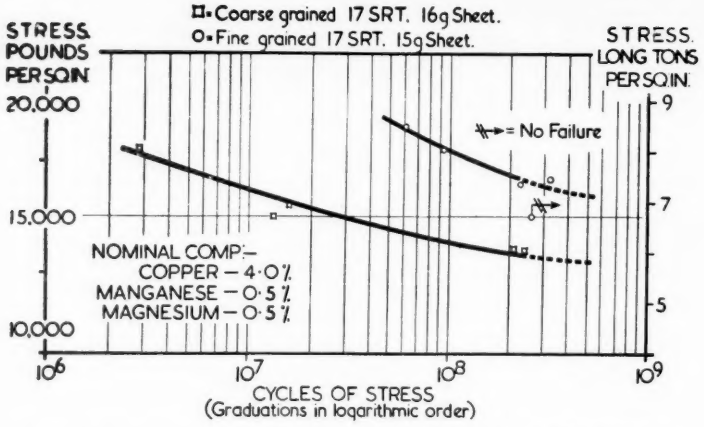


Fig. 13. Sheet metal fatigue curves for fine and coarse grained alloy 17 S.R.T.

Another material in which a crack has developed is shown in Fig. 9 (p. 431), from the Royal Aircraft Establishment. The alloy is L38, *i.e.* clad Duralumin and the crack and the earlier developed slip bands are clearly seen.

Figure 10 (p. 431), also from the Royal Aircraft Establishment, shows the progressive development of a crack as a result of cyclic stresses. The alloy is Duralumin. The start of the crack should be noted, and the fact that it avoids the inter-metallic inclusions.

Figure 11 (p. 431), from the Aluminum Company of America, shows the development of a complex system of cracks in a cyclicly stressed cantilever beam. The alloy is 17S, roughly equivalent to the British L1 or L3. The maximum skin stress was 5.8 tons/in.^{2} and the stress reversals were 5.6×10^6. The following points are noteworthy:—

(*i*) The cracks do not follow inter-crystalline boundaries but traverse crystals.
(*ii*) They tend to stop at an inter-crystalline boundary.
(*iii*) They avoid inter-metallic inclusions.
(*iv*) The direction of the cracks can scarcely be described as at right angles to the principal stress, although it might have been imagined that failure would have taken place due to the development of a single crack in such a direction. This, however, would have been an undue simplification of a problem which abounds in complexities.

The question arises of why plastic flow ever starts at stresses below the engineers' elastic limit. The answer is—because of local, and often extremely local, stress concentrations. Leaving out those due to design, of which there are a great many, they can arise from

(*a*) random arrangement of anisotropic crystals,
(*b*) mixed phases of differing elastic characteristics,
(*c*) inclusions differing physically from the matrix,
(*d*) residual stresses, and
(*e*) discontinuities.

SOME IMPORTANT INFLUENCES

Some small mention will now be made of three important matters in relation to the influence of some micro-structures on fatigue:—

(*i*) Variation in crystal size
(*ii*) Precipitation hardening
(*iii*) Inclusions.

Variation of crystal size

Probably the greatest extremes are found in the ferrous field. Crystals of as much as 10 in. long sometimes occur in the very largest mild steel castings, while those in a wrought nickel chrome steel may be as small as a ten thousandth of an inch.

In the wrought aluminium field great variation in grain size is also a matter of

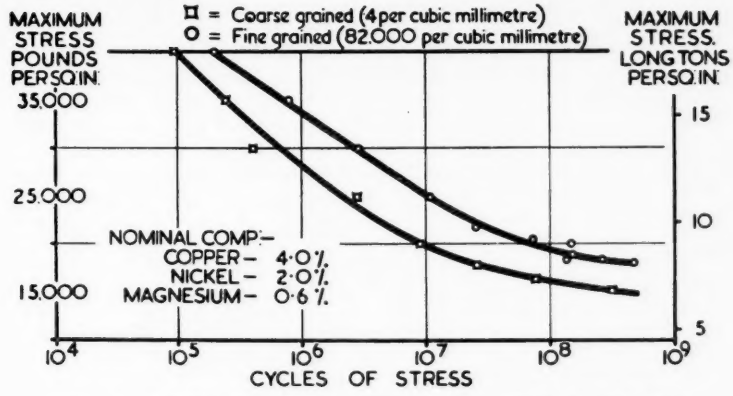


Fig. 14. Rotating beam fatigue curves showing effects of grain size, aluminium alloy 18 S.-T.6.

common experience. This is shown in Fig. 12 (p. 430), where the alloy is D.T.D. 364 and the extrusion is square in section, being about 3×3 in. The coarse outer crystals and the finer core should be noted.

The next three figures relate to the influence of the variation of grain size on the fatigue endurance of three different wrought aluminium alloys. In each case in which a comparison is made, the specimens have the same chemical composition and very nearly the same ultimate tensile stress.

The curves of Fig. 13 are taken from R. L. Templin's notable A.S.T.M. paper of 1933. The alloy is approximately L3, *i.e.* 17S in America, and the ratio of the average diameters of coarse to fine grains is about four to one. At 10^8 stress reversals the endurance limit of the coarse grain alloy is about 4,000 lb./in.^{2} lower than that of the fine. 10^8 reversals might be considered an unreasonable number, but the Aircraft Industry has certainly shown considerable reticence in stating what *is* a reasonable number.

The curves of Fig. 14, from the Aluminum Research Laboratories, are for the alloy 18S, approximately forged "Y" alloy. The ratio of the average diameters of coarse to fine grains is approximately 27 to one and, at 10^8 stress reversals, the endurance limit of the coarse grain alloy is about 3,000 lb./in.^{2} lower than that of the fine.

The curves of Fig. 15 are from James Booth & Co. Ltd., the first company to make Duralumin in England. The alloy is extruded L40 and the ratio of the average diameters of coarse to fine grains is about 15 to one. At 10^8 stress reversals, the endurance limit of coarse grain alloy is about 8,000 lb./in.^{2} lower than that of the fine.

To summarise the effect of grain size:—

(*i*) With ferritic steels, and possibly with ferritic steels alone, grain size does not appear to have much effect on fatigue.

(*ii*) With austenitic steels, coarse grain decreases the fatigue limit.

(*iii*) With some coarse grain alloys the decrease in fatigue resistance is proportional to that in ultimate stress, while with others this is definitely not so.

(*iv*) Even in the same alloy group, relative grain size provides no real arithmetical

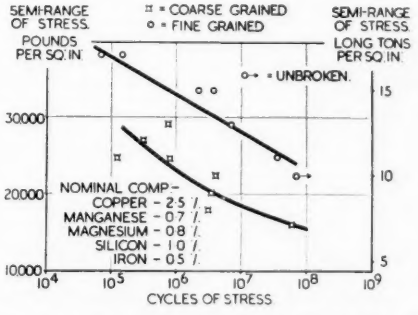


Fig. 15. Rotating beam (Wöhler) curves for coarse and fine grained specimens from the same 4 in. × 4½ in. L.40 extrusion.

guidance as to relative fatigue endurance.

(*v*) All that can be said on the basis of existing knowledge is that fatigue resistance of fine-grained material (other than ferritic steel) is better than that of coarse-grained material of the same chemical composition and physical antecedents.

Precipitation hardening

Since precipitation-hardening alloys are used extensively in aircraft, a summary is given of current ideas as to the mechanism of such hardening, before describing its effect on fatigue characteristics:—

(*i*) The precipitate does not occupy the same volume as it did when in solution.

(*ii*) Therefore the dimensions of precipitation-hardened alloys are not quite the same as they possessed in the solution-treated condition.

(*iii*) The extremes of linear alterations arising from precipitation hardening, as so far determined, lie between 20 and 1,000 parts per million. With Duralumin, according to the author, this change is 95 per million.

(*iv*) Precipitation hardening gives rise to highly localised internal stresses.

(*v*) It greatly increases static mechanical strength.

Regarding the effect of precipitation hardening on fatigue characteristics, Table II gives a general answer with regard to the three alloys

beryllium-copper,

aluminium - copper - manganese - magnesium, *i.e.* 14S or D.T.D. 364,

magnesium - aluminium - zinc - manganese, *i.e.* AZ91 or D.T.D. 136B.

Table II needs careful study and the following points should be noted:—

(*i*) The tremendous rise in yield stress due to precipitation hardening with beryllium-copper and 14S or D.T.D. 364.

(*ii*) The modest rise in endurance limits with both these alloys.

(*iii*) The fall in endurance limit with the magnesium - aluminium - zinc - manganese alloy.

Summarising:—

(*i*) Precipitation-hardened alloys do not invariably possess their greatest resistance to fatigue when in the fully heat-treated state.

(*ii*) When an alloy possesses its highest resistance to fatigue in the fully heat-treated state, this superiority is often small.

Inclusions

Inclusions can be divided into at least three main classes:—non-metallic, metallic and inter-metallic. The first can be likened to dirt, that is, to matter in the wrong place, and examples are

(*i*) slag and flux,

TABLE II

CHANGES IN MECHANICAL PROPERTIES ARISING FROM PRECIPITATION HARDENING

Alloy and Physical Condition and Authority	*Nominal Composition*	*Ratio of New Properties to Original Ones*		
		Yield Stress	*Ultimate Stress*	*Endurance Limit* (50×10^7)
Solution - treated wrought beryllium-copper strip (J. T. Richards)	Be 2.5% Cu remainder	4.6	2.3	1.1
Annealed 14S bar (Alcoa)	Cu 4.4% Mn 0.8% Mg 0.4% Si 0.8% Al remainder	4.3	2.6	1.4
As cast magnesium alloy (Magnesium Elektron)	Al 9.5% Zn 0.4% Mn 0.3% Mg remainder	1.4	1.6	0.9
Solution-treated magnesium alloy (Magnesium Elektron)	As above	1.3	1.0	0.8

(*ii*) oxides, nitrides, phosphides and sulphides, and so on.

Metallic inclusions are generally intentional additions to molten alloys to facilitate subsequent machining. Examples have already been given.

Inter-metallic compounds are characteristic of the precipitation-hardening alloys and of very many others like the bearing metals, and so on.

All inclusions are born into a world of falling temperature and of increasing rigidity, which prompts the following physical questions:—

(*i*) What are the relative coefficients of contraction of inclusion and of surrounding metal? If the inclusion has the greater coefficient of contraction, it may become detached like a kernel in a nut. Alternatively, if the inclusion has the smaller coefficient of contraction then, with falling temperature, it must surely become a centre of increasing residual stress?

(*ii*) If the coefficients of contraction are about the same, what is the inter-facial relationship of the inclusion to the surrounding metal? Is there cohesion between the two, or merely contact?

(*iii*) What are the relative elastic and plastic characteristics of inclusion and surrounding metal?

(*iv*) If there is cohesion between the two then, unless their elastic moduli and elastic limits are about the same, the application of any external force must surely produce inter-facial stresses?

SUB-DIVISION OF INCLUSIONS

For the present, inclusions may be divided into two classes

(*a*) malign,
(*b*) benign.

Fig. 16 (p. 431) is a section of a crankshaft which failed by fatigue and is an example of (*a*). The crankshaft, which was case-hardened, was of composition—carbon 0.1 per cent., nickel 3.4 per cent., chromium 0.8 per cent. There is a fatigue crack emanating from one of several inclusions, and the inclusion is a silicate one.

As an example of a benign inclusion, Fig. 17 (p. 432) shows an unetched specimen of a free-cutting mild steel. Its sulphur content is 0.15 per cent. and the phosphorus content 0.1 per cent. and the inclusions are manganese sulphide. Fig. 18 (p. 432) is an unetched specimen of a steel of approximately the same composition except that its sulphur and phosphorus contents are both of the order of 0.03 per cent. The fatigue limit of this steel, both in the longitudinal and transverse directions, is *not* better than that of the free-cutting one.

It would indeed be satisfactory if inclusions could be simply divided into malign and benign. Unfortunately, however, both classes have Jekyll and Hyde characteristics. While silicate inclusions reduce fatigue resistance of strong steels, particularly if they have an ultimate tensile stress of 80 tons/in.^{2} or more, in wrought iron and mild steel they are innocuous, unless perhaps occurring at a zone of great stress concentration.

Lead in both steel and brass is, in the normal quantities, without adverse influence on the fatigue characteristics of these alloys. However, it reduces the fatigue resistance of aluminium alloys. This anomaly is readily explicable because the evil influence of an inclusion depends not only on its own qualities, but on those of the surrounding metal. If this possesses what, in 1931, Moore termed "crackless plasticity," harm is unlikely to arise from the average inclusion unless perchance this occurs at a zone of stress concentration.

A brief word is necessary on the shape of inclusions, which is best illustrated by Fig. 19 (p. 432), due to W. W. Braidwood and A. D. Busby, of a hypo-eutectic cast iron. The upper portion shows characteristic graphite flakes. The lower portion is the same cast iron except for the addition in the ladle of a small quantity of a nickel-magnesium alloy; the graphite is now spheroidal. Both specimens had the same ultimate tensile stress, but the endurance limit of the spheroidal iron was 5,000 lb./in.^{2} higher.

Summarising, the influence of inclusions on fatigue resistance depends on their size, shape, number and distribution, and on their physical characteristics in relation to those of the alloy in which they occur.

CONCLUSION

In the view of the author and for the reasons given, such is the complexity of stress distribution *within* any metallic component that to avoid all risk of its failure by fatigue, realistic testing is the sole insurance.

REFERENCE

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Design Problems for Interceptor Fighters

by

Lieutenant Commander J. S. BAILEY, O.B.E., R.N.

1. INTRODUCTION

This paper does not claim to reveal any epic discoveries. In fact the technical features discussed, if perhaps not well tried are certainly well known to designers and technicians in aeronautical development. Its purpose is rather to emphasise the need for concentration in development in certain directions in the light of up-to-date combat experience with the aid of rather limited, but surprising, information on design trends of modern enemy interceptor fighters.

It is hoped that this will assist the operators, who will readily appreciate the tactical aspects, to assimilate some of the technical implications and to be able to discuss them more freely with designers and technicians.

2. DISCUSSION

It is well known that jet aeroplanes operate most economically, from a fuel consumption point of view, at their service ceiling and that with fighters the struggle for altitude supremacy has always been paramount from the beginning. Therefore performance at maximum altitudes is of first importance.

In recent years engines have developed to the extent that there is excess power available with straight-wing aircraft beyond the Mach number limit in level flight at any altitude. While this excess power is always usable for increasing rate of climb, all other limitations on performance are dependent on airframe design.

With swept-wing aircraft, on the other hand, the Mach number limit being higher, it is possible to exceed a height where the engine efficiency has fallen and thrust is not available to achieve Mach number limit in level flight.

There is very little scope for improving Mach number limits of Service fighters beyond 0.93, or for Delta wings 0.95, while still remaining a satisfactory gun or air-to-air missile platform and being free from compressibility effects. Any substantial improvement would require the wing section to be so thin as to involve considerable stressing problems and would extend the take-off and landing runs beyond reasonable limits.

3. RELATIVE PERFORMANCE OF FRIENDLY AND ENEMY FIGHTERS

A study of the relative performance of United Nations and Communist swept-back fighters gives an interesting comparison. The enemy fighters have proved themselves tough customers and when properly handled and employed are in most respects superior.

Basically the power ratings are similar, excepting that the U.N. aircraft has water methanol injection and at low altitude gains a superiority of 16 knots, whereas at 40,000 ft. the enemy aircraft has 18 knots advantage, due partly to the relative ineffectiveness of water injection at height; in particular the enemy aircraft has a very favourable weight advantage in a ratio of 10,000 to 16,000 lb. with a similar internal fuel capacity, giving wing loadings of 45 against 60 lb./ft.^{2} respectively.

This remarkable difference in weight is due partly to the heavier axial flow engine of the American fighter but almost certainly due mainly to a lower stressing factor in the Soviet aircraft. U.N. fighters are stressed to withstand a 12 *g* loading, whereas the Soviets are believed to build to a factor of about 8 *g*, a practice which was followed by Japanese designers. While Asiatics are prepared to accept an occasional loss due to fatigue of materials or defects in manufacture for the sake of a large weight reduction, it has never been the policy of the Allies to accept such

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Lt.-Cdr. Bailey is at present serving in H.M.S. *Ocean*.

Paper received April 1952.

The opinions expressed and the statements made in this paper are solely the author's responsibility.

risks. Therefore it follows that, given a parity in engine output and aerodynamic form, the Asiatics will invariably gain in performance in all conditions of flight.

Assuming that the United Nations maintain a lead in engine design the advantage will still be in favour of the lighter aeroplane at high altitudes, due to the drop in air density, (*a*) because the optimum lift/drag ratio with full power will occur at a lower altitude with the heavier aircraft and therefore it will have a lower Service ceiling, (*b*) the overall loss of thrust for engines of different rating will be in reduced proportion to their sea level performance. Even for two aircraft with an equal thrust to all-up weight ratio, but of lower wing loading, (*a*) and (*b*) will still apply.

Notwithstanding this, the aircraft with the lower wing loading will have the advantage in manoeuvrability at all heights, regardless of thrust/weight ratio, within the range met in modern interceptor practice.

4. WEIGHT-SAVING POLICY

It is not contemplated or recommended that the problem should be solved in the manner of the Asiatics. It is true that technical developments are continually taking place in an attempt to reduce aircraft weight. Considerable weight reductions could even now be achieved by a revision in conventional design and construction methods by the following methods:—

(*a*) Simplification of fuel systems by the policy of reserving a large volume of the fuselage for fuel space and inserting separate compartments for such spaces as required by the cockpit, radio equipment, landing gear and jet pipe. This would reduce the large number of tanks that are found tucked away in all sorts of obscure places, not to mention overload tanks (one British jet aircraft has seven separate internal fuel tanks), and the multiplicity of fuel and vent pipes, non-return valves, drain cocks, selector cocks, fuel gallerys inversion pumps, restrictors, filters and venting valves.

(*b*) Stressing of every detail of construction rather than just the main components; although such a process is very expensive and requires a vast stressing staff (regrettably a great shortage exists in Great Britain), it will save a large amount of unwanted weight.

(*c*) Use of plastic mouldings in various constructional ways should be thoroughly investigated.

Such methods as in (*a*) and (*b*) have already been employed with great success by an American firm and in one example of a Navy Attack aircraft a bomb load of 40 per cent. of the normal service load, which includes fuel for 1,500 miles range, has been achieved. The British Navy counterparts are in the region of 15 per cent. bomb load to normal service load, even for the Royal Navy's latest strike aircraft. This enterprising American firm has produced a turbo-prop attack aircraft which, it is claimed, can carry a greater war load than any known jet fighter or bomber for the same expenditure of fuel.

Such weight-saving design methods have not generally been applied to Allied jet fighters, though undoubtedly such a policy would be more than justified.

Any appreciable reduction in weight will automatically involve a reduction in wing span for a given wing loading, and any reduction in wing span will involve a further reduction in weight, because a smaller amount of structural material will be required for a given stressing factor. Therefore there is a progression in weight loss, a highly desirable feature.

5. ROCKET MOTORS AND AFTERBURNERS

Some prototype fighters and experimental aircraft have flown with liquid fuel rocket motors as a subsidiary means of propulsion, the thrust being roughly the same as that of a gas turbine. Like the turbo-jet engine they depend upon Newton's law of motion, *i.e.* every action has an equal and opposite reaction, but unlike the turbo-jet a rocket motor is not dependent upon air density and therefore, as the aeroplane drag falls off with height so the rocket motor effectiveness increases where the turbo-jet would progressively lose efficiency.

The use of rocket motors for high-altitude interceptors, where the extra thrust available would enable the fighter to exceed the normal Mach number limit and fly through the compressibility effects at the transonic region, has undisputed advantages, particularly as other enemy aircraft would be flying at or about a similar subsonic Mach number limit at such altitudes. The rocket motor will consume a vast quantity of fuel in a very short time and

will occupy space and weight otherwise used for jet fuel.

It can be assumed then that the rocket motor will be used for making contact with the enemy, but once the precious rocket fuel is consumed, normally after 5 to 10 minutes, the fighter will be faced with the same problems as the pure turbo-jet aircraft and therefore all the weight saving advantages will still be applicable. Moreover, during conditions of actual rocket propulsion weight saved in construction will be weight available for extra fuel, or improved manoeuvrability.

Afterburning is another means of providing a substantial but short-period increase in thrust at the expense of a high consumption of fuel. Being in effect only a booster to the turbo-jet it will suffer proportionate disadvantages at altitude and can only be considered as second to a rocket motor.

6. CHOICE OF MATERIALS FOR CONSTRUCTION

The Soviet swept-back fighters have a main spar of high grade steel, a complete departure from accepted constructional design methods. High grade tensile steel can give a higher bending moment than Dural, weight for weight, but in shear and torsion the stresses are lower. A swept-back wing requires to be stronger and therefore heavier than is really necessary in order to be sufficiently stiff; perhaps this is the reason for steel. Possibly the production of steel main spars is quicker and less costly, or the reason may be a shortage of suitable light alloys in the U.S.S.R.

7. GUIDED MISSILES

There is always the prospect that supersonic ground-to-air guided missiles capable of immense manoeuvrability may one day oust the pilot-controlled interceptor. Homing and guiding devices completely free from outside interference are an ever present problem in design and it appears most unlikely that any foolproof devices produced will remain immune indefinitely. So long as there are pilot-controlled bombers or pilot-controlled parent aircraft carrying air-to-ground guided weapons it would seem logical to continue with all expediency the development of pilot-controlled interceptors.

CONCLUSIONS

U.N. swept-back fighters have been largely successful in combat because they possess a better gunsight and have better disciplined flight tactics. Even so, Soviet swept-back fighters have some markedly superior features. It is popularly supposed that the enemy fighter has a higher powered engine; the fact is that the power ratings are similar, but the Allied fighter has better performance at low altitudes due to water methanol injection, which loses most of its effectiveness with altitude, and the enemy has superior speed and manoeuvrability at height. These advantages are attributed to the Soviet aircraft's lower wing loading which is in the ratio of 45 to 60 lb./ft.^{2}.

This large disparity in weight is believed to be due to a policy of building to a much lower stressing factor. U.N. designers should give more detailed attention to a vigorous weight-saving policy, otherwise they will always be at a disadvantage. An appreciable weight saving will give increased Service ceiling, better manoeuvrability and performance at all altitudes. Moreover any weight saved in construction will result in reduced wing span, which in turn will reduce weight of construction material required for a given stressing factor.

The criterion for interceptor fighters is a high Mach number limit combined with low wing loading to give maximum advantage, particularly at high altitudes where combat normally occurs. Because of the uncertainty of homing and guiding devices for ground-to-air guided missiles being permanently immune from outside interference there cannot, as yet, be any thought of abandoning pilot-controlled interceptors.

*Problems of Short-Haul Air Transport**

by

PETER W. BROOKS, B.Sc., A.C.G.I., A.F.R.Ae.S.

1. INTRODUCTION

The first part of this paper discusses some fundamentals of Air Transport and shows how these affect the organisation of airline operators. Against this background, Part II examines some of the particular problems of the short haul operator—the side of the Industry with which the author has been associated in British European Airways.

PART I

2. AIR TRANSPORT TODAY

Commercial Air Transport has existed for more than thirty years. It has made important progress, but has still a long way to go to fulfil its destiny. Although progress in developing the vehicle since the first aeroplane flew in 1903 has been highly spectacular, Air Transport itself has made a slow start. This is shown by Fig. 1 which compares the increases in passenger traffic that occurred in the first thirty years of British rail and air transport.

In spite of this modest beginning, air traffic is now expanding at an astonishing rate and the aeroplane has recently assumed a commanding place in long-distance passenger transport.

In 1951, the airlines of the world carried about 40 million passengers. More non-Tourist Class traffic crossed the Atlantic to Europe by air during the year than by sea. For the first time a British airline carried more than a million passengers in twelve months and was the first operator outside the United States to do so.

On the fare structure that has existed since the 1939-45 War, passenger air traffic has increased at an average rate of about 17 per cent. per annum. In 1951 it increased by 25 per cent. The traffic carried by United Kingdom and United States operators in the past thirty years is shown in Fig. 2.

The recent decision to introduce Tourist Fares in 1952 and 1953 is an important step to further progress. It is estimated that, provided political and economic conditions remain reasonably stable, traffic in Europe will be doubled by the new fares in two years—and perhaps doubled again in another two.

These portents of the future suggest that within a few years the large majority of passenger journeys of more than 200-300 miles will be made by air. Perhaps within a few decades a majority of passenger journeys of more than 20-30 miles may be by helicopter.

At the present time, outside the Soviet bloc, more than one hundred scheduled air carriers operate some 2,600 aircraft over a route network of nearly 1¼ million miles—more than the world's total railway mileage. Fig. 3 shows the relative scale of output of the world's largest airlines in 1950, the latest year for which complete figures are available. The ascendency of the United States in air transport is clear. This leadership extends at present to providing the majority of the world's transport aircraft. American influence and example in all branches of the Industry have been profound. If Great Britain is to challege this lead it can only do so by enterprise and effort in the operating as well as in the manufacturing sphere.

3. TYPES OF OPERATION

The organisation of the world's operators, the types of their equipment, the forms of

*A Section Lecture read before the Society on 31st January 1952.

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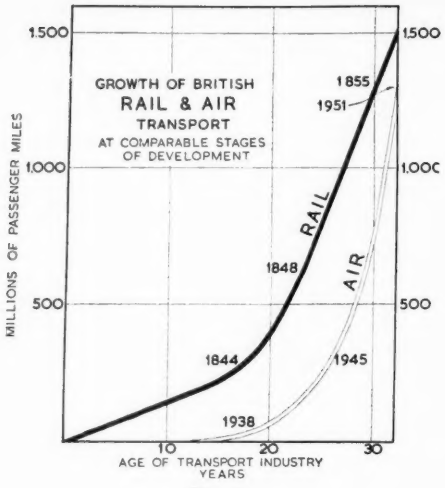


Fig. 1.

route network, the lengths of stage, the density of traffic, the ground facilities available, the standards of service and the rates charged, all vary widely and sometimes in an unrelated manner. In spite of these divergencies, their activities are governed by the same general principles and it is possible to classify them into four broad types, defined by the sector lengths operated. These are shown in Fig. 4.

Such a classification cannot be rigid but it does help to show the basically different problems of the various types of operation. These may be for the carriage of passengers or freight or, as is usually the case, a combination of both.

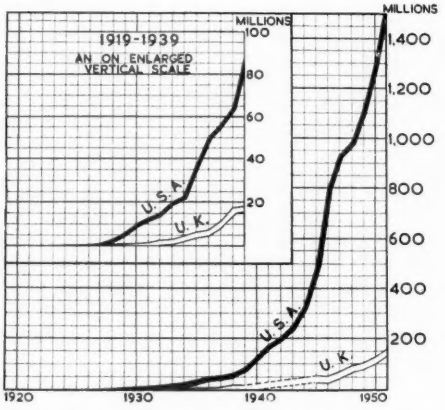


Fig. 2. United States and United Kingdom airlines; load ton-miles operated.

The influence of sector length on the economics of operation is illustrated by an interesting comparison made recently by Colin McIntosh, of the American local service operator All-American Airways[1]. He compared five hypothetical airlines. Two were feeder operators serving networks with average stage lengths of 60 and 100 miles, two were short-haul operators with average stage lengths of 150 and 500 miles and the fifth was a long-haul operator with an average stage length of 2,000 miles. The feeder and short-haul operators were assumed to use DC-3s and the long-haul operator DC-4s.

Making assumptions in line with American experience for all five carriers and assuming the same scale of operation, McIntosh concludes that the different operators would achieve the financial results shown in Fig. 5. This conclusion—which confirms B.E.A. experience—reflects the basically uneconomic character of short-stage operation and underlines the influence of sector length on the economics of Air Transport.

4. SHORT-HAUL OPERATIONS

Some of the reasons for the less economic character of short-haul operations are summarised below. The cost per ton mile on short hauls is fundamentally higher than on long hauls because:—

(1) The high incidence of landings in relation to miles flown causes:—

(*a*) Low block speeds— the time allowances represent a high proportion of block time.

(*b*) Low aircraft utilisation—higher proportion of time spent on the ground; more serious effect of "non-commercial" hours in the day.

(*c*) Low crew utilisation—low ratio of crew flying time to total working time.

(*d*) Higher secondary crew costs—more crew transport, night stopping and other expenses per mile flown.

(*e*) More difficult aircraft and crew integration—aircraft and crews must operate more sectors per day.

(*f*) Reduced aircraft serviceability—aeroplanes usually go unserviceable on the ground rather than while flying.

(*g*) Increased maintenance — more frequent take-offs and landings per hour flown increase wear and tear.

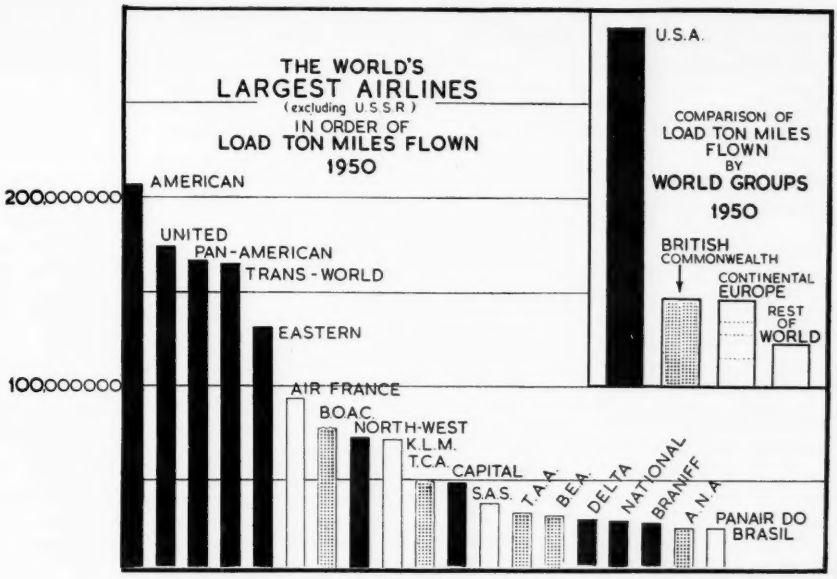


Fig. 3.

TYPE OF OPERATION	TYPICAL AIRCRAFT USED	TYPICAL OPERATION	ROUTE PATTERN
LONG HAUL LONG STAGE over 2000 miles	STRATOCRUISER CONSTELLATION DC-6	BOAC ATLANTIC	
LONG HAUL MEDIUM STAGE 1000 - 2000 miles	CONSTELLATION DC-6 DC-4 HERMES 4	BOAC EMPIRE ROUTES	
SHORT HAUL 200 - 1000 miles	DC-3 DC-4 CONVAIR 240 VIKING LANGUEDOC	BEA CONTINENTAL	
FEEDER under 200 miles	DC-3 RAPIDE DOVE BEAVER	BEA SCOTTISH NETWORK	

Fig. 4. Types of air transport operation.

(*h*) More serious effects of bad weather—lower regularity and punctuality; proportionately longer Air Traffic Control routeings and holding times.
(*i*) Proportionately heavier fuel reserves—at the expense of payload.
(*j*) Proportionately heavier fuel consumption—the fuel allowances represent a higher proportion of fuel burned.
(*k*) Need for a fixed (or relatively more fixed) booking payload giving overall payload penalties — because of the difficulties of using fully variable fuel loads or variable routeings.
(*l*) For a given route density, higher station costs per mile flown—there are more stations per mile of route.

(2) Short sectors result in:—
(*a*) Higher costs for passenger and crew meals and amenities per mile flown—because a meal has often to be served even on the shortest sectors.
(*b*) Disproportionate sales effort to sell a given capacity—because the absolute time saved by Air Transport is less on a short journey and the absolute saving is what matters most to the traveller.
(*c*) Greater loss of passenger goodwill from irregularity and unpunctuality—because delays tend to be a greater proportion of the journey time.
(*d*) A higher proportion of seasonal holiday traffic—giving uneconomic peaks and troughs in the traffic flow. There are also more marked weekly peaks for the same reason.

(3) For a given airline output, the larger number of passenger, freight and mail movements means more traffic, sales, accounting and statistics staff—many costs are proportionate to number of passengers handled while revenue is proportionate to passenger miles flown.

(4) There is a higher proportion of "thin" sectors, particularly on "spoke" networks. For adequate frequency of operation this may mean smaller, and therefore less economic aircraft, or larger types at uneconomic load factors.

(5) The proportionately wider spread of sector lengths makes it more difficult to match aircraft to route. Aircraft can therefore only be operated less frequently near their optimum sector distance.

(6) For a given traffic flow on a route, higher frequencies are usually desirable. For satisfactory load factors, this means smaller aircraft which are basically less economic than larger units.

(7) An even greater effort for safety is vital to an airline making many landings in a year. Most airline accidents are associated with the take-off and landing cycle and the frequency with which an airline has an accident counts most in its impact on passenger opinion.

With all these disadvantages, short-haul Air Transport remains pre-eminently worthwhile. This is the field in which there is the greatest traffic potential and, in the long term, that which will provide the greater part of the "big business" of the Industry. The way may be hard, but the prize is great.

5. THE ROUTE NETWORK

Another fundamental of Air Transport which influences an airline's mode of operation and its economic results is the type of route network. Again, it is difficult to place every operator into any one group, but most

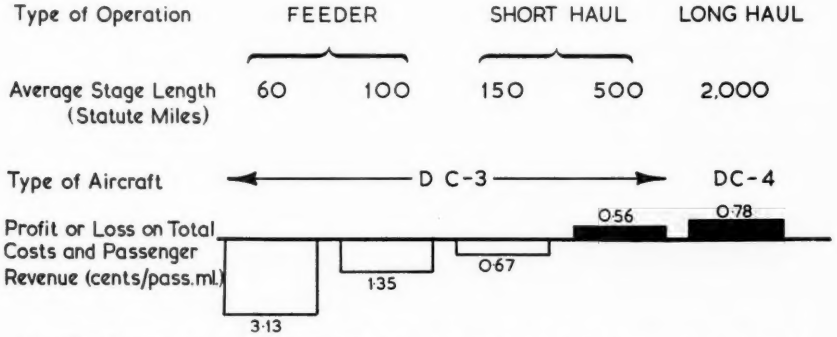


Fig. 5. Comparison of economic results of different types of air transport operation[1].

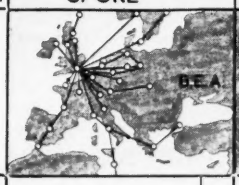
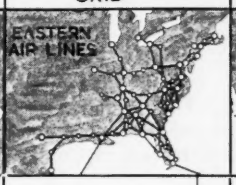
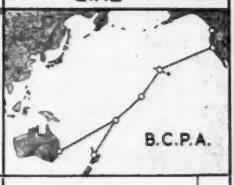
TYPE OF NETWORK	SPOKE		GRID		LINE	
TYPICAL ROUTE PATTERN						
AIRCRAFT & CREW UTILISATION	DIFFICULT		EASIER	✓	EASY	✓
TRAFFIC FLOW THROUGH STATIONS	LOW EXCEPT AT HUB		HIGH	✓	LOW	
ENGINEERING	CENTRALISED	✓	DISPERSED		TERMINAL ONLY	
NIGHT STOPPING AND CREW SLIPPING	COSTLY		CHEAPER	✓	COSTLY	
BAD WEATHER	SERIOUS IF AT HUB		LOCALISED EFFECT ONLY	✓	SERIOUS AT ANY POINT	
MOVEMENT CONTROL	EASIER	✓	COMPLEX		EASY	✓
SALES EFFORT	CONCENTRATED	✓	DISPERSED		DISPERSED	

Fig. 6. Types of route network.

route patterns have an affinity with one of three simple types. These are:—

(*i*) The "*Spoke*" network—of which B.E.A's operations are an example.

(*ii*) The "*Grid*" network—such as that of Eastern Air Lines.

(*iii*) The "*Line*" network—of which British Commonwealth Pacific Airlines are a classic example.

Some of the characteristics of each type of route network are set out in Fig. 6.

6. AIRLINE ORGANISATION

The various types of operation and route network have now been considered. These together, whatever the character and volume of traffic carried, constitute the primary operational problem. They dictate the form of every airline's organisation. Yet within the limits set by their varying influences, it is possible to distinguish a uniform basic pattern in the administrative structure of all air transport undertakings.

All airlines can be regarded as having two productive Divisions (Fig. 7) each of which has two merging roles:—

(1) The Technical and Operational.
(2) The Traffic and Commercial.

In other words:—

Making the aircraft available and flying them.

Handling the traffic after finding it.

For most airlines each of these functions is discharged by one or more Departments which are supported by ancillary Departments responsible for:—

(3) Finance and Economic Control.
(4) Staff and Property.

The Technical, Operational, Traffic and Commercial roles of an airline are the directly productive side of its activities. They include:—

(*a*) Procurement of aircraft, other equipment and stores.
(*b*) Aircraft maintenance, overhaul and inspection.
(*c*) Flight operations.
(*d*) Movement control.
(*e*) Space and reservations control.
(*f*) Traffic handling.
(*g*) Sales and sales promotion.
(*h*) Advertising.

These functions follow from each other and interlock. At the top of the list the aircraft are made available; at the bottom the traffic is attracted. The aircraft, provided by the Engineering side of the airline and operated by the Flying Staff, are controlled from day to day by Movement Control to schedules agreed with the Traffic and Commercial sides of the organisation. The traffic, attracted by Advertising and acquired by Sales, is handled by the Traffic Handling organisation and integrated by Space and Reservations Control into schedules agreed with the Technical and Operational Division.

Thus, the schedules—applied by Movement Control and exploited by Space and Reservations Control—are the centre of the airline's productive effort. The effectiveness of this scheduling and the manner in which it is planned, governs an operator's efficiency more than any other single factor.

In addition to the two main productive Divisions, and the ancillary Departments which support them, an airline requires a number of subsidiary Branches. These Branches, some of which are shown in Fig. 7, are all part of the Head Office organisation and perform indirectly productive and staff functions. Most of them are associated with, and come within the framework of, one or other of the main Departments already considered.

The administration of the stations on an airline's network is additional and outside the structure described above. Administrative control of staff at stations is usually vested in the Traffic Department because the majority are traffic personnel. Nevertheless, outstations may also have engineering, sales and space control functions. Staff engaged in these activities must obviously have close contacts with their specialist Head Office organisations. A common arrangement is for outstations administrative staff to come under Traffic while reporting for all specialist matters to the appropriate part of Head Office. Fig. 8 shows a typical way in which executive responsibilities are delegated and gives the numbers of staff controlled by each Department in the B.E.A. organisation.

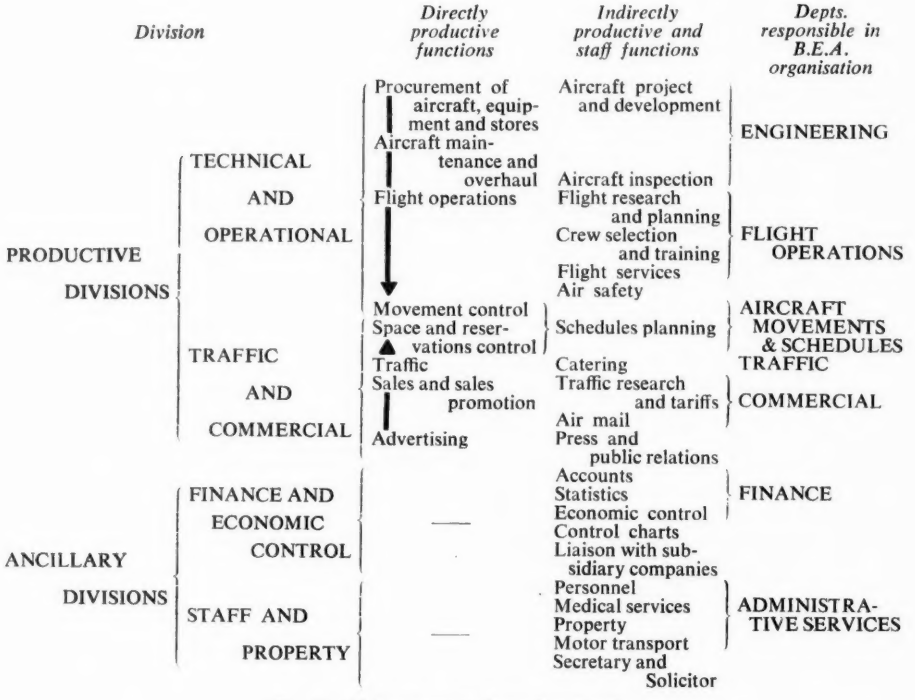
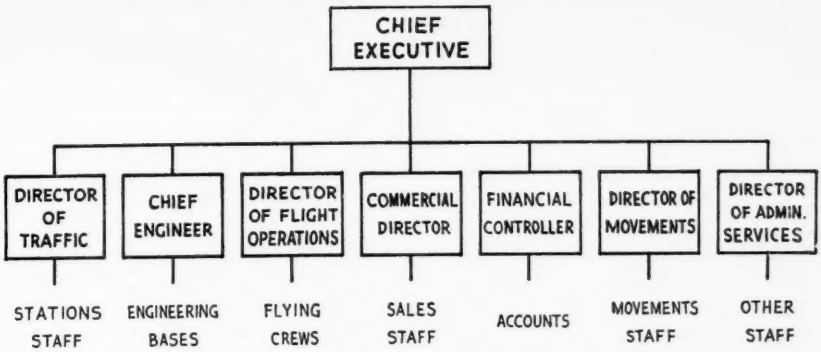


Fig. 7. Airline organisation—functional.



	STATIONS STAFF	ENGINEERING BASES	FLYING CREWS	SALES STAFF	ACCOUNTS	MOVEMENTS STAFF	OTHER STAFF
NUMBERS OF STAFF IN B.E.A.	3184	2275	985	162	582	338	472
PERCENTAGE OF TOTAL	39·5%	28·3%	12·2%	2·1%	7·3%	4·2%	5·9%

Fig. 8. Airline organisation—executive responsibility.

7. B.E.A.'s ORGANISATION

The form of organisation is particularly important to the short-haul and feeder operator to whom an efficient and economic structure is essential to counteract the basically more costly nature of such services.

B.E.A. apportions functions and administrative responsibilities in the manner shown in Figs. 7 and 8. The resulting organisation is more clearly depicted in Fig. 9. This organisation tree shows that B.E.A. has seven main Departments each headed by a Director reporting directly to the Chief Executive. Each Department is itself sub-divided into Branches under Managers reporting to their respective Directors. In this organisation Aircraft Movements and Schedules are given the prominence and centralised treatment which they deserve. The Traffic Director administers the Stations—in other words he is the executive head of the staff manning the network.

8. HOW IT ALL BEGAN

As we have seen, Air Transport is only some 32 years old. In this connection it is interesting to recall that the first serious airline undertaking was formally registered as a Company in 1916, and only came into effective existence shortly after the end of the First World War. On 25th August 1919, this company—Air Transport and Travel Ltd.—operated between London and Paris the first scheduled daily air service in the world.

In May 1918, before the end of the First World War the man primarily responsible for this pioneer interprise, the late George Holt Thomas read a classic paper, "Commercial Aeronautics," before the Royal Aeronautical Society[2]. In it he outlined his plans for starting an airline. From these far-sighted hypotheses has sprung the great industry of today.

PART II

1. PARTICULAR SHORT HAUL PROBLEMS

The particular problems of the short-haul operator considered here can be conveniently divided under three heads:—

(1) Aircraft development.
(2) Operational application.
(3) Economic control.

The development of the vehicle has been, and remains, the controlling factor in the progress of Air Transport. Although the possibilities and limitations of the vehicle prescribe what is attainable in all forms of transport at any given time this applies with even greater force in the case of Air Transport. To get this fact into perspective it is useful to consider for a moment how the short-haul and feeder transport aeroplane has evolved.

Fig. 9. B.E.A. Administrative Tree.

JUNE 1952

2. AIRCRAFT DEVELOPMENT

To become an effective means of transport, the aeroplane had to reach a size at which it was capable of carrying a number of passengers. Although the first aeroplane flew in 1903, it was not for about 10 years that aeroplanes capable of carrying several passengers were produced.

Tsarist Russia was the birthplace of the true forerunner of the modern airliner. Igor Sikorsky, who in more recent years has done so much to develop the helicopter, flew his "Grand" four-engine aeroplane for the first time near Leningrad on 13th May 1913. This aeroplane, although clumsy in appearance and performance, was outstandingly successful and on one occasion carried eight people on a flight of nearly two hours.

In England perhaps the first notable landmark in the development of transport aircraft was the Grahame-White "Char-a-bancs" which carried a pilot and nine passengers on a single 120 h.p. Austro-Daimler engine on 2nd October 1913. However, the Admiralty started the most significant line of development. In December, 1914, the Admiralty Air Department approved a specification which became the basis of the 0/100, Handley Page's "Bloody Paralyzer" which first flew on 18th December 1915. This was the forerunner of the 0/400, the most successful Allied heavy bomber of the 1914/18 War which was subsequently developed into a long line of multi-engine bombers and transport aeroplanes used by many of the world's pioneer airlines. The line has continued down to the Hermes 4 medium-stage transport used by B.O.A.C. on the African services today.

While the First World War was still in progress, in April, 1918, two 0/400s began the first cross-Channel air service carrying ferry pilots to France. The War over, Handley Page lost no time in applying the 0/400 to civil purposes and from it developed the W.8b—one of the first really successful transport aeroplanes.

Imperial Airways Ltd. was formed by the Government in 1924 to take over the services of the various private operators which had started Air Transport in Great Britain after the First World War. This company, at first using W.8bs and a number of small single-engined types, devoted its early years to the development of short-haul routes in Europe. In 1931, as a result of this experience, Imperial Airways introduced the Handley Page Heracles. This was a 38-passenger aeroplane intended specifically for high traffic density short-haul routes which, in spite of its "built-in headwinds," marked an important step in development. It was the first truly commercial short-haul aeroplane.

The Americans got off to a slow start in Air Transport and initially lagged behind European countries. Seriously behind the other Great Powers in aircraft design at the end of the 1914-18 War, they at first confined themselves to a Trans-Continental mail service operated by the Post Office with converted military aeroplanes of basically British design. Gradually in the late 1920s passenger services began to open up across the American Continent and multi-engine transport aeroplanes of their own design were produced. From 1928 the upswing in passenger traffic on the U.S. internal services was very marked and these soon became a remarkable "forcing ground" of Air Transport.

In 1930 developments in the United States led to changes in airframe and power plant design which started a revolution in the growing industry. In the late 1920s and early 1930s most aeroplanes were still biplanes built up from duralumin or steel tubing or rolled sections covered with fabric. Such monoplanes as were already in use at this time—notably Dutch and German designs—did not provide, either structurally or aerodynamically, any great advance on the more common biplane.

In the early 1930s, these older forms of construction were gradually superseded by new techniques which, although pioneered in various countries, were first applied to transport aircraft in America. The new design philosophy not only incorporated a more modern structure and a more refined aerodynamic form, but it also included a number of other vital design improvements—flaps, retractable undercarriages and variable pitch airscrews.

The Boeing Monomail of 1930 was, perhaps, the first aeroplane of the new era. It had a cantilever low wing with a smooth stressed duralumin skin. Although a single-engined aeroplane with accommodation for only six passengers it had a retractable undercarriage and led directly to the Boeing 247 twin-engine ten-passenger transport of 1932.

The Douglas Company's reply to this aeroplane was the DC-1, soon developed into

the 14-passenger DC-2 of 1933 and its famous successor, the 21-passenger DC-3 of 1935. These aeroplanes pioneered the short-haul air transport of today. With this equipment the American internal airlines expanded rapidly and led to the evolution of Air Transport as a stable, and gradually more profitable, industry.

The early 1930s also saw a new and significant development in Great Britain. Until this time transport aeroplanes had tended to grow larger, more elaborate and more powerful as knowledge of aircraft design progressed. From about 1931, however, small companies began to start up internal airlines in Great Britain. In doing so they created a new side to the Industry. Their needs led to the development of a new class of small, cheap-to-operate transport aeroplane of which the de Havilland Dragon of 1932 was one of the first and most successful examples. The British Aircraft Industry soon made this class of aeroplane a British speciality and this country has maintained its lead in this field to the present day.

For the short-haul routes in Europe in the later 1930s Imperial Airways ordered the de Havilland Albatross and Armstrong Whitworth Ensign four-engined monoplanes which had retractable undercarriages, flaps, and variable pitch airscrews in the new style. Unfortunately the Second World War prevented these aeroplanes from justifying their promise. It also caused the cancellation of two newer designs, the Short S.32 (14/38) and Fairey FC-1 (15/38), which were ordered in 1938. These aeroplanes were a "lost generation" in the development of British transport aircraft, the effects of whose loss are still very much with us today.

Their contemporary in America, the Douglas DC-4 prototype first flew on 30th May 1938. Seen against the rapid progress of the American domestic operators using the well-established DC-3, this aeroplane created a great impression abroad. As it turned out, it did not appeal in its original form to the American operators, but a re-designed slightly smaller version—the DC-4A—flew in April 1942 and was an immediate success. After the Americans had entered the War a military transport version of the DC-4A was built and, like the DC-3, was used for War purposes on an enormous scale.

The DC-4 was the first aeroplane of the modern four-engine formula, just as the DC-3 before it had been the first to establish a lasting design philosophy in the two-engine class. It is not too much to say that these two aeroplanes, in their respective categories, brought Air Transport into the modern era.

In the United States the Convair 240 and Martin 202 and their developments have continued the DC-3 formula. The DC-4 has been followed by the first truly long-stage transport aeroplanes—the various versions of the Lockheed Constellation and Douglas DC-6 and the Boeing Stratocruiser.

In the United Kingdom, in 1943, the Brabazon Committee was set up by the Government of the day to examine British requirements for post-War transport aircraft. Besides long-haul types to challenge the American successors to the DC-4, two short-haul aeroplanes have resulted from its recommendations. The de Havilland-Airspeed Ambassador and the Vickers-Armstrongs Viscount are now in production and are to come into service as the B.E.A. Elizabethan and Discovery Classes in 1952. Two feeder aircraft also grew from Brabazon Committee Specifications. Both the de Havilland Dove and the Handley Page Marathon have gone into production, the former achieving service in large numbers. From the Dove has been developed the Heron—another promising aeroplane now in production.

In concluding this outline of aircraft development, it is well to look for a moment at the overall picture of progress in Great Britain and to see whether it holds any lessons for the future.

Figure 10 shows the gross weight of British transport aircraft plotted against the date at which they came into service. The curves indicate the increasing weight of aeroplanes used for each basic type of operation over the years.

Today, the United Kingdom has the opportunity of assuming world leadership in the manufacture of transport aircraft. The Bristol Britannia, the de Havilland Comet and the Vickers Viscount can become pre-eminent in each of the three more important categories. There is no reason why the long-established lead in the fourth, feeder, class should not be maintained as well. By its efforts since the Second World War the United Kingdom has gained itself a great opportunity. This can only be exploited by:—

(*i*) Production in adequate numbers, and
(*ii*) Energetic further development.

GROWTH IN SIZE
OF
BRITISH TRANSPORT AIRCRAFT
1919-1954
MAXIMUM GROSS WEIGHT (LB.)
140,000
130,000
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
1920
1930
1940
1950
WORLD WAR II
LONG HAUL
LONG HAUL
MEDIUM STAGE
SHORT HAUL
FEEDER
BRISTOL 175
D.H. 106 COMET
H.P.81 HERMES 4
AVRO 688 TUDOR 4
AVRO 685 YORK
AIRSPEED A.S.57 AMBASSADOR
VICKERS V.701 VISCOUNT
VICKERS V.610 VIKING
H.P.M.69 MARATHON
D.H. 114 HERON
PERCIVAL PRINCE
D.H. 104 DOVE
AIRSPEED A.S. CONSUL
BRISTOL 170 WAYFARER
FAIREY O F.C.1
SHORT S.32 14/38
SHORT S.26 GOLDEN HIND
A.W.27 ENSIGN
SHORT S.23 EMPIRE
D.H.91 ALBATROSS
SHORT L.17 SCYLLA
A.W.15 ATALANTA
D.H.95 FLAMINGO
D.H.86B
D.H.89 RAPIDE
AIRSPEED A.S.6 ENVOY I
H.P.45 HERACLES
A.W. ARGOSY II
AVRO 652 AVALON
D.H.84 DRAGON
SHORT S.8 CALCUTTA
A.W. ARGOSY I
D.H.66 HERCULES
H.P.W.10
H.P.W.8B
D.H.34
H.P. O/10
VICKERS VIMY
D.H.16

Fig. 10.

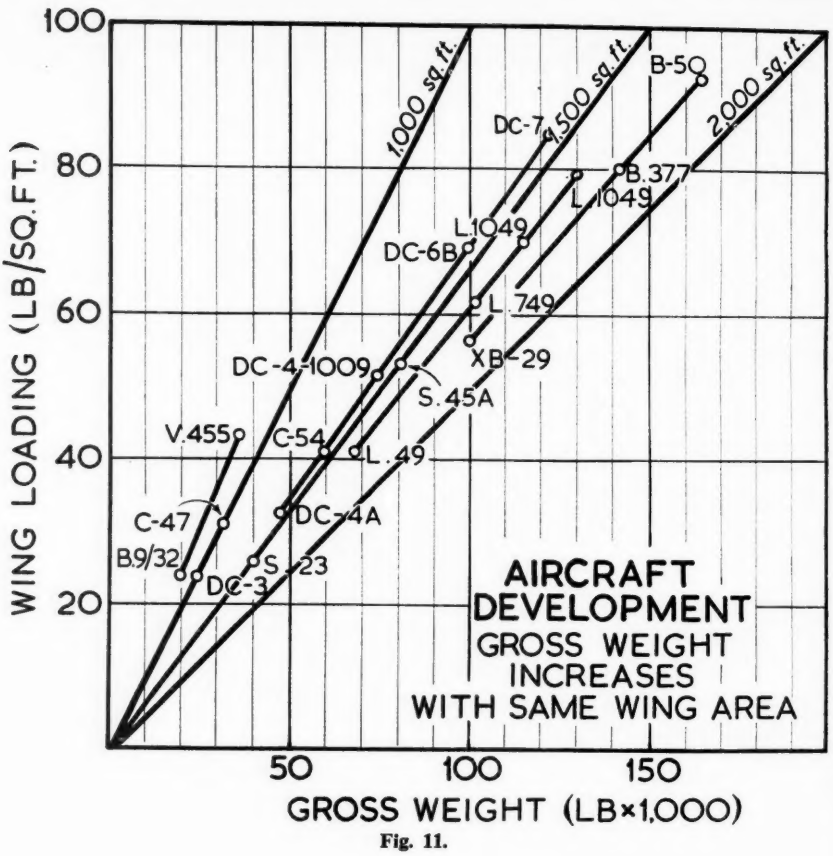


Fig. 11.

It must be hoped that, in spite of the calls of defence, both these essentials can be met. While production is the basic problem facing the whole Aircraft Industry, development is perhaps a less obvious necessity. Its importance for transport aircraft is shown, however, by American experience. The Americans have achieved their leadership in the manufacture of transport aircraft as much from their continuous "stretching" of a few successful basic designs, as from any inherent quality of those original designs. The same policy must be adopted in this country. Fig. 11 shows how the gross weights of some well-known aircraft have been progressively increased with development so that greater and greater loads have been carried with the same basic wing. The economic benefits of such a policy have been remarkable.

3. THE COMMERCIAL HELICOPTER

Another field in which the United Kingdom has a great opportunity is in the application of the helicopter to transport purposes. The helicopter is as well suited to transport requirements here as the aeroplane is to the geography of the United States.

On internal services within the British Isles the aeroplane suffers from the fundamental disadvantage that sectors are too short for the air travel time between city centres to show any striking advantage over the highly developed surface transport system. Only on sea crossings does the air journey offer any substantial saving, but unfortunately most of such routes suffer from a preponderance of highly seasonal tourist traffic.

Because of these factors, transport by aeroplane inside the United Kingdom will never assume the proportionate volume or importance of air transport in such places as the United States or Australia. At best, it can perhaps be made to pay its way on the trunk short-haul services. The feeder routes must inevitably continue to depend on Government subsidy.

All this emphasises the need to press forward with the development of the commercial helicopter. When further developed, this promises to be no worse economically than the aeroplane while offering a complete solution to the problem of reducing journey times on short sectors (Fig. 12).

To come into its own the helicopter must, as a start, achieve standards of reliability, regularity and punctuality comparable with those already attained by the aeroplane. In the long run, it must aim to be at least as independent of weather conditions as competing surface transport. Acceptable standards in these fields are attainable only with a great deal of further development. A prolonged period of experimental scheduled operation is also essential.

B.E.A. has appreciated the importance of the helicopter and has been preparing for some time to go over to this new vehicle on the majority of routes of less than about 300 miles as soon as development of the aircraft makes this possible. To gain essential operating experience, the B.E.A. Helicopter Experimental Unit has been busy for the past four years preparing the ground by running experimental services. On the basis of this experience, B.E.A. is planning to introduce the Bristol 173 twin-engined helicopter into service in 1954. In addition, the Corporation has recently issued a specification for a 35/45 passenger helicopter for service from about 1960[3].

To gain some idea of the economic potentialities of the helicopter and to help to visualise how its technical development may influence its suitability as a transport medium, a comparison has been made between a large helicopter, such as might result from the B.E.A. Specification, and the Sikorsky S.51 three-passenger helicopter used on the experimental services of today. The large helicopter is considered in two forms:—

Case A—a 36-passenger aircraft of a type which might be in service in 1960, and

Case B—a 45-passenger development which might be available in the more distant future.

Both versions are assumed to be shaft-driven with piston engines and auxiliary fixed wings to unload the rotors in cruising flight. Turbines, with or without tip-drive, may well have proved themselves by the 1960s. If they have, they should materially improve the picture, making the comparison as it stands unduly conservative. Certainly, in the long run, the helicopter can only achieve its full potentialities by the development of

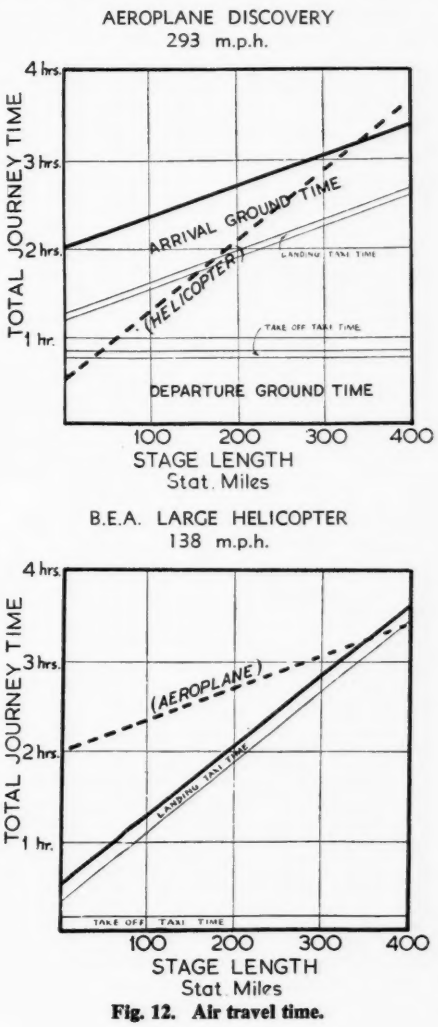


Fig. 12. Air travel time.

AIRCRAFT TYPE	DE HAVILLAND D.H16	HANDLEY PAGE HERACLES	D.H.-AIRSPEED AMBASSADOR	SIKORSKY S.51	B.E.A. LARGE HELICOPTER (CASE A)	B.E.A. LARGE HELICOPTER (CASE B)
Year in service	1919	1931	1952	1950	1960?	1965?
Engines	1 × Eagle 9	4 × Jupiter 10	2 × Centaurus 661	1 × R-985-B4	4 × Leonides	4 × Leonides Major
Total Take-off power (b.h.p.)	360	2,220	5,400	450	2,400	3,600
Maximum Take-off weight (lb)	4,400	29,500	52,500	5,300	24,000	36,000
Passenger seating capacity	4	38	49	3	36	45
Commercial cruising speed (m.p.h.)	95	100	234	90	138	150
COMPARISON ON LONDON-PARIS ROUTE						
Payload (lb)	650	7,280	10,250	700	4,800	8,100
Average block speed (m.p.h.)	81	86	153	80	120	130
Average time between city centres (hrs)	4·14	3·75	3·25	3·00	2·09	1·95
Variable cost/C.T.M. (1952 pence)	138·30	38·85	23·95	131·4	49·0	29·6

Fig. 13. Aeroplane and helicopter development comparison.

specialised power units suited to its particular requirements.

Figure 13 tabulates the general characteristics of the three helicopters and for comparison gives details of three piston-engined transport aeroplanes used at similar periods in fixed-wing development.

The D.H.16 was a four-passenger conversion of the D.H.9A bomber of the First World War. It had a single 360 h.p. Rolls-Royce Eagle engine and can therefore be regarded as the fixed-wing equivalent of today's Sikorsky S.51 at a similar period in the aeroplane's development. The Handley Page Heracles was representative of the large transport aeroplane when it first reached an economic size for trunk short-haul operations. A helicopter of the type visualised in the B.E.A. Large Helicopter Specification might be expected to reach a similar state of development by about 1960. Finally, details are given of B.E.A.'s Elizabethan Class Ambassador transport now coming into service for comparison with a more fully developed large helicopter.

Some idea of the comparative economic characteristics of these six aircraft types is shown by Fig. 14. The variable costs of each type, on a common standard of 1952 £ Sterling, have been estimated for the London-Paris route. It will be seen that far from being hopelessly uneconomic, the helicopter holds promise of ultimately becoming as economic as the fixed-wing transport.

4. THE BALANCE OF PAYLOAD AND FUEL

Turning to the operational application of the vehicle in the role for which it has been developed, payload/fuel determination is discussed briefly.

The balance of payload and fuel carried in an aeroplane is the controlling factor in its utility as a vehicle. This relationship is the

basic parameter in its design and the skill with which the balance is maintained in service has an important influence on the economics of its operation.

In the early days of air transport, aeroplanes lacked sufficient range for reasonable regularity on quite short stage operations. In other words, a strong headwind would sometimes mean that the aeroplane had not enough range to fly the sector. The drawback of lack of range was aggravated by low cruising speeds which meant that variations in wind seriously interfered with regularity and punctuality.

Gradually these difficulties were overcome and, by the time aeroplanes had developed to an economic size giving capacity of 30 to 40 passengers, ranges had increased sufficiently for regular operation on sectors of 400-500 miles. At this time the short-haul operation of today became possible.

Fuel loads at this time were quite arbitrarily determined. At first, every operation was started with full tanks. Then, gradually, fixed amounts of fuel for each sector were adopted. Fuel reserves were initially governed by the tankage available and were unrelated to any defined idea of what contingencies they were intended to cover. They simply provided the Captain with fuel in hand beyond the normal requirement. With this margin he had to make the best of any adverse circumstances that might arise.

As experience increased and aeroplanes began to require larger, and therefore less generally available, landing places and were operated to higher standards with better navigational facilities and more elaborate aids, fuel loads were related more accurately to each sector. Fuel reserves also came to be governed by more practical considerations. Nevertheless a "fixed" conception for each sector persisted. The Captain, when the aeroplane had sufficient tankage, gradually assumed the responsibility for taking on more fuel above the amount fixed should he judge that conditions made such a step prudent. Such procedures have persisted until recently for short and medium-stage operations.

Shortly before the Second World War, when the first long-stage operations started across the Pacific and Atlantic Oceans,

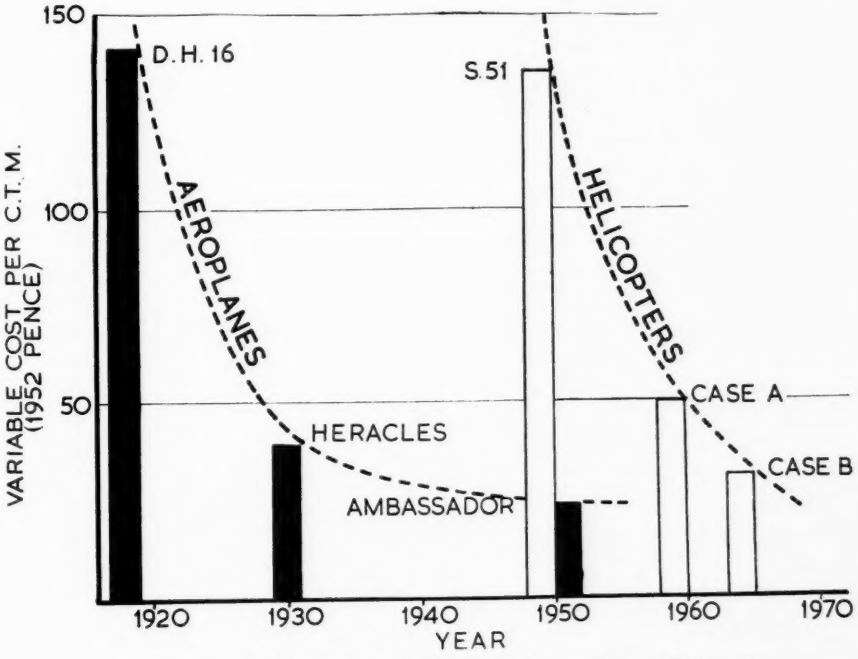


Fig. 14. Variable cost per C.T.M. Comparison on London-Paris route.

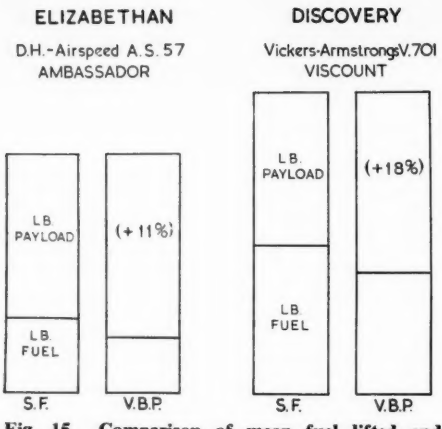


Fig. 15. Comparison of mean fuel lifted and payload, London-Zurich, 495 statute miles, with Sector Fuel (S.F.) and Variable Booking Payload (V.B.P.) methods.

variable fuel loads and special cruise control procedures began to be used commercially for the first time. These techniques were greatly developed during the War and have since become universal practice for long-haul operation.

In spite of these developments, fixed sector fuels have continued to be used on short hauls because of the difficulty of applying such complicated practices to high frequency services. However, a change is now imminent. The economic benefits that can result from variable fuel loads—even on short sectors—are so great that they can no longer be ignored.

The Variable Booking Payload Method[4] now being developed by B.E.A. has the objective of relating fuel loads to the significant variables after assessing them accurately. The method entails appropriate cruise control procedures and ways of exploiting commercially the varying increases in payload that result from varying the fuel lifted. The problems involved are now well on the way to solution.

The economic benefits in the operation of piston-engined aircraft will be substantial. They will be even more important when turbine aircraft enter commercial service. In addition, operating standards will be still further improved because of the greater precision of each operation.

Figure 15 shows a typical reduction in fuel load on a stage length of about 500 miles that can result from using the Variable Booking Payload Method instead of Fixed Sector Fuels, for the Elizabethan and Discovery. The piston-engined aeroplane shows an 11 per cent. increase in payload; the turbine aeroplane, an 18 per cent. increase. The economic benefits of such increases in payload are obvious.

5. ECONOMIC CONTROL

In conclusion some problems of the economic control of air transport operations are considered.

Air transport is a commercial activity and one that—at least in its long and short-haul form—can be made economically self-supporting. To become so, however, it requires skilful management, the right equipment and an organisation appropriate to the operating task. Also needed are ways of controlling

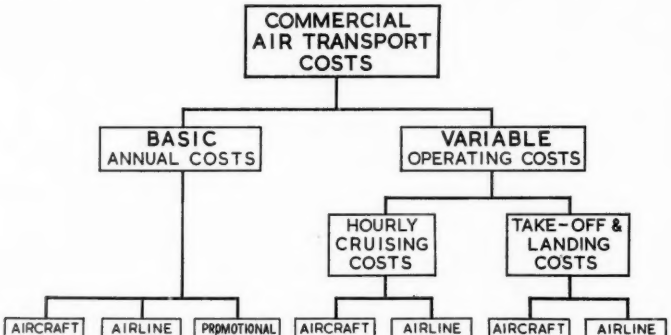


Fig. 16. Costs family tree—commercial air transport.

both day-to-day progress and longer term development in the light of changing traffic requirements and varying economic conditions.

Something has been said already of the organisation aspects of commercial, operational and engineering control. Beyond and above these, the management of an airline requires an overall picture of what is happening and—even more important—must be able to see the economic implications of what is done. This means that it is necessary to have at Head Office a sufficiently accurate picture of costs and revenues, broken down under suitable headings, for those responsible to be able to draw conclusions from trends and then to act upon them in good time.

This time factor is important. Air Transport is an essentially modern activity; it is volatile and dynamic in character and shows this in the way it responds to varying conditions and changing circumstances. This is particularly true of short-haul operations. To be effective, day-to-day control must be based on a system of information which works both promptly and continuously.

A most important feature of such a system of information is the cost breakdown on which it is based. The breakdown being used in B.E.A. has been evolved from that originally advocated by P. G. Masefield in 1948[5]. This method was intended originally to provide convenient and realistic cost approximations on which to base economic comparisons of aircraft types.

The basis of the method was twofold.

First, it introduced the conception of three kinds of cost—the Basic Annual Costs (overheads), the Variable Costs related to hours flown and the Variable Costs related to the number of landings made. The breakdown is shown diagramatically in Fig. 16. The third factor, the Take-Off and Landing Cost, was new. Its introduction brought into air transport costing for the first time the full effects of stage length.

Second, it related different cost items to the factors influencing them more completely than had been attempted before. Previous airline costing methods had evolved very largely from American railway practice and related costs to ton miles as a single basic unit. It is interesting that very soon after Masefield made his suggestions for a change, the American Inter-State Commerce Commission published a report on railway costing procedures in which they advocated a similar alteration in the treatment of railway costs.

Masefield described the method, as now developed for cost control purposes, in his Brancker Memorial Lecture before the Institute of Transport in 1951[6]. He has subsequently discussed further aspects in articles in *The Aeroplane*[7]. It would take too much space to consider the method in detail here, but there are two aspects of it which may be touched on briefly.

6. METHODS OF COST ANALYSIS COMPARED

An interesting feature of the B.E.A. Cost Method is the introduction of a breakdown into Aircraft, Airline and Promotional Costs. These sub-divisions have extended the utility of the developed method beyond those of purely airline costing to cover more

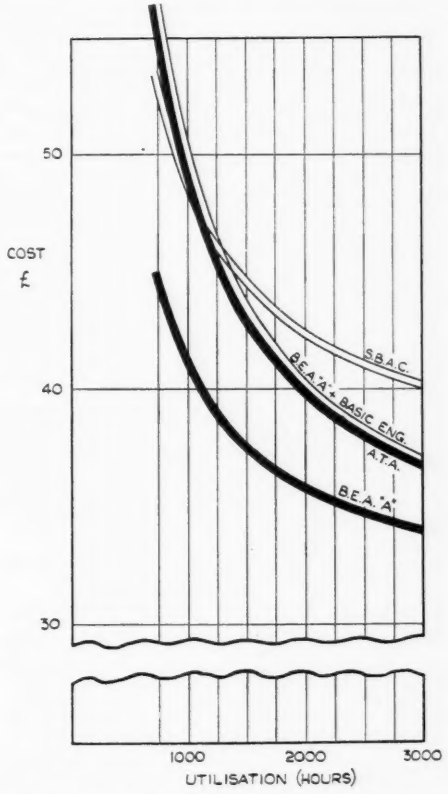


Fig. 17. Cost per flying hour: Effect of utilisation (stage length: 215 miles).

effectively the purpose for which the original method was evolved—purposes also served by the American A.T.A. and British S.B.A.C. cost formulae.

The Aircraft Costs of the B.E.A. Method —like those produced by the A.T.A. and S.B.A.C. Methods—can be regarded as those relating directly to the aircraft type and are therefore useful for analysis and assessment of the economics of different aircraft.

There is a good deal of practical evidence to support the figures arrived at by the B.E.A. Method so that if generalised results of Aircraft Costs of the Viking on B.E.A.'s International routes, analysed by the B.E.A. Method, are compared with those resulting from the A.T.A. and S.B.A.C. formulae, an interesting indication is obtained of the validity of the A.T.A. and S.B.A.C. formulae as applied to actual short-haul operations.

Figure 17 shows the effect on costs, determined by the three methods, of varying the aircraft utilisation of the Viking operated on the London-Paris route. It will be seen that both the A.T.A. and S.B.A.C. Costs come out higher than the B.E.A. Aircraft Costs. This is not in itself important for the comparative purposes for which these formulae are used, but it is essential that such estimated costs should bear a constant relationship to actual costs. Fig. 17 compares costs derived by the S.B.A.C. formula with the comparable B.E.A. Aircraft plus Basic Engineering Costs. It shows that, if the B.E.A. costs are a reliable guide, the S.B.A.C. formula does not give a true picture of the effect of utilisation. The A.T.A. formula, which like the B.E.A. Aircraft Costs, does not include Fixed Engineering, is also unrealistic.

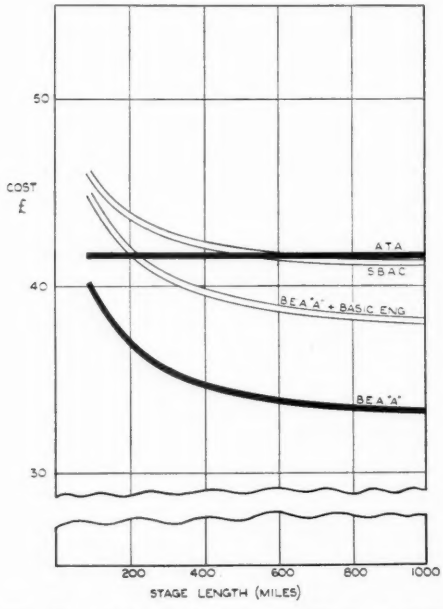


Fig. 18. Cost per flying hour: Effect of stage length (utilisation: 1,750 hrs.).

Figure 18 shows the cost per flying hour of B.E.A. Vikings operated on varying stage lengths on International routes at a utlisation of 1,750 hours per annum. The curves show that the A.T.A. formula, because it ignores landing costs, is most misleading. It gives a constant cost per flying hour for all stage lengths. The S.B.A.C. formula is a better guide, although it also errs on short stage lengths.

To sum up. On the basis of B.E.A. experience, the A.T.A. formula appears to interpret wrongly the effect of variations in both aircraft utilisation and stage length. The S.B.A.C. formula, while being a marked advance on the American method in the way in which it reproduces the effect of stage length, would still appear to distort the effect of aircraft utilisation, particularly for short-haul operations.

7. ROUTE CONTROL

The most important application of a Costing Method used for control purposes is in the rapid presentation of information for short-term management decisions. B.E.A. have concluded that, for short-haul and feeder operations, this must be done on a route basis. The results of each route are examined separately and its progress summarised in graphical form. Fig. 19 shows the presentation adopted for each route.

On the left is the *statistical picture*. From top to bottom are the Load Factors (both actual and to break even), the Capacity Ton Miles (C.T.M.) and the Load Ton Miles (L.T.M.) (the capacity offered and sold), and the Traffic Ton Miles achieved. Both Moving Annual Totals and Monthly Totals are used.

On the right is the *financial picture*. At the top are Expenditure and Revenue, then the overall Profit or Loss, the Specific Cost and Revenue in relation to output and finally

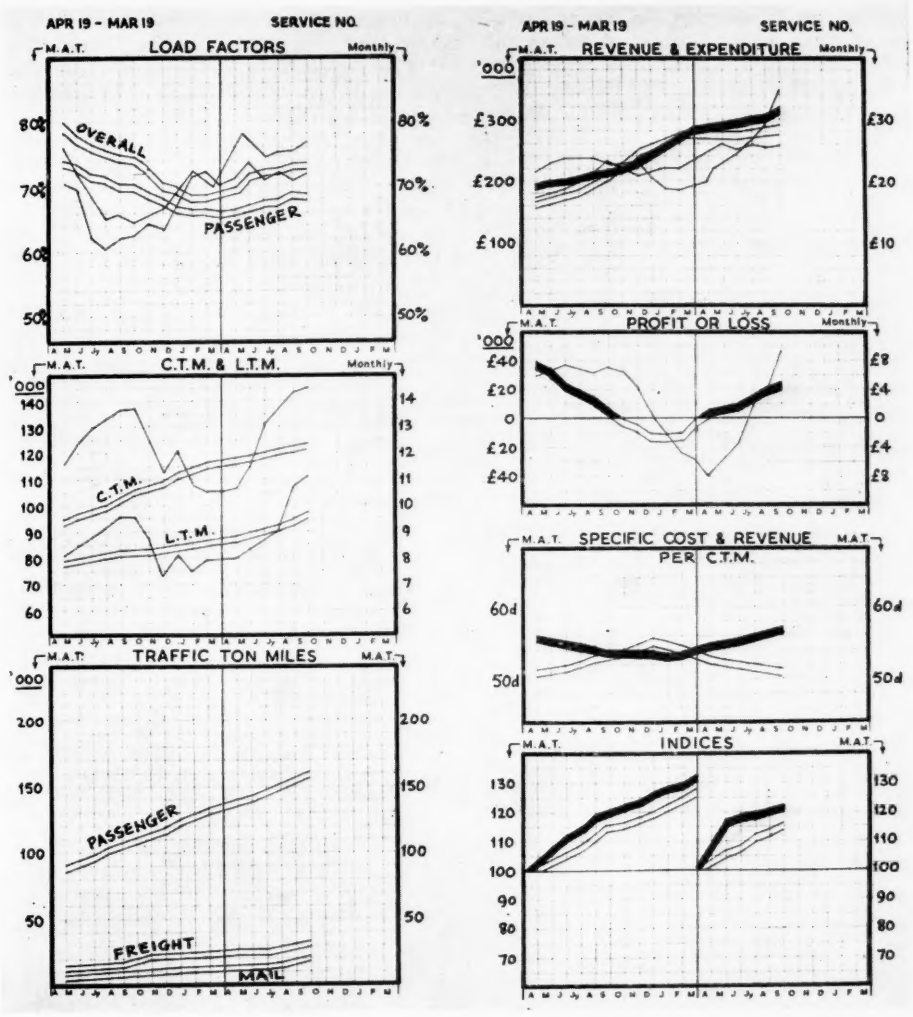


Fig. 19. Route results.

an index presentation to show trends of the important variables in relation to each other.

Three different levels of cost for each route must be related to revenue for the various kinds of economic control required. These are:—

(*i*) Total Cost.
(*ii*) Critical Route Operating Cost.
(*iii*) Marginal Cost.

Total Costs, the route's share of the airline's total expenditure, are used to give an overall picture of how the route is faring in relation to the rest of the network. Such a total cost figure involves allocation of overheads to each route. This is done mainly on the basis of the gross weight and budgeted hours of the aircraft used.

For most control purposes it is unnecessary, and can be misleading, to consider the airline's overheads in the route picture. Instead, *Critical Route Operating Costs* are used. These costs comprise the Variable

Costs of the Route plus the Basic Aircraft Costs—the Standing Charges of the aircraft used. The C.R.O. Costs can be regarded as those that must be covered by Revenue if the route is to contribute over a period to the airline's overheads. In other words, they are the costs that must be covered to justify operating anything more than purely *ad hoc* services.

Marginal Costs are those that must be covered to justify a particular service. In other words, they are the costs directly related to an individual flight which must be covered by the revenue earned by that service for it to be economically justified.

Such a presentation of information about each route enables Head Office to visualise the complete operating picture and to decide quickly when to shift an emphasis of effort, how to economise, where to expand.

8. CONCLUSION

Air Transport is one of the most complex forms of modern industry but one destined to meet the essential need for improved communications as part of human progress.

In this brilliant future the United Kingdom can take a leading part if the lessons of recent years are carefully studied and the Manufacturing and Operating Industries go forward in mutual confidence and understanding. The Manufacturing Industry has designed and proved the contemporary tools that the Operators need. It must now be given the opportunity to produce them in adequate numbers and to continue developing them to keep pace with the calls of the future.

The Operators must be allowed to work out their own destinies with a minimum of political interference. Their greatest need is for understanding and support as much from their own countrymen as from their Governments. In the fiercely competitive world of Air Transport only the efficient and enterprising can long survive—and then only when they spring from a nation with faith in its future in the Air.

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Notes on the Mean Aerodynamic Chord and the Mean Aerodynamic Centre of a Wing

by

A. H. YATES, B.Sc., A.F.R.Ae.S.

SUMMARY

The relations between the various reference chords used in reports on the loading of wings (standard mean chord, mean aerodynamic chord, centroid of area chord, and so on) are reviewed. Formulae are given for the position on these reference chords of the mean aerodynamic centre of certain simple "additional" load distributions. References to convenient methods of calculating the load distribution on an arbitrary wing are also given.

1. INTRODUCTION

In making longitudinal stability calculations it is commonly assumed that any wing can be replaced by an equivalent unswept rectangular wing and that, if the latter is located with a suitable x co-ordinate, the two wings will behave identically as regards lift and pitching moments. For example, A.P.970 defines a "standard mean chord" of length $\bar{c}=S/b$ placed with its quarter-chord point at

$$\bar{x}_{1/4}=\frac{\int_{-b/2}^{+b/2} cxdy}{\int_{-b/2}^{+b/2} cdy}=\frac{\int_{-b/2}^{+b/2} cxdy}{S}.$$

It is implied that calculations of pitching moment and lift based on the rectangular wing with this chord will apply to the original wing. This is not usually correct and now that highly swept wings are common it may be much in error, and a closer examination of the problem is advisable.

NOTATION

A	wing aspect ratio $(b/\bar{c})$
b	wing span
c	local wing chord, measured parallel to the plane of symmetry
c_r	root chord
c_t	tip chord of a wing of uniform taper
$\bar{c}$	length of standard (geometric, average) mean chord $=S/b$
$\bar{\bar{c}}$	length of mean aerodynamic chord $=\frac{1}{S}\int_{-b/2}^{+b/2} c^2dy$
C_{la}	local "additional" lift coefficient
C_{lb}	local "basic" lift coefficient
C_L	total lift coefficient

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C_l	local lift coefficient
C_{m0}	local pitching moment coefficient at zero lift
$\overline{C}_{m0}$	total pitching moment coefficient at zero lift
h	(distance aft of leading edge)/chord
h_0	location of the local aerodynamic centre, measured as h ($h_0=0.25$ approximately and is often assumed to be 0.25)
$h_{c.p.}$	(distance of wing c.p. aft of leading edge of C.A.C.)/(length of C.A.C.) (*see* end of Notation for definition of C.A.C.)
S	gross wing area
OX	axis in the plane of symmetry of the wing parallel to the wing no-lift line and parallel to which all chord lengths are measured, positive towards trailing edge
OY	axis normal to the plane of symmetry of the wing through the wing root leading edge, positive to starboard
x, y	co-ordinates of the local aerodynamic centre measured parallel to X and Y
$\bar{x}, \bar{y}$	co-ordinates of the mean aerodynamic centre
η	$y/(\frac{1}{2}b)$
$\eta_{c.p.}$	(spanwise co-ordinate of centre of pressure of half wing "additional" load)/$(\frac{1}{2}b)$
λ	taper ratio, c_t/c_r for a wing of uniform taper
Λ_{h0c}	angle of sweep of line of aerodynamic centres
$\Lambda_{c/4}$	angle of sweep of line of quarter-chord points
Λ_{LE} or Λ_{TE}	angle of sweep of wing leading edge or trailing edge
M.A.C.	mean aerodynamic chord
S.M.C.	standard mean chord
C.A.C.	centroid of area chord.

2. EQUIVALENT WINGS

Assume that the wing has a plane of symmetry and consider the lift and pitching moment properties of the two half-wings shown in Fig. 1.
The two wings shown in Fig. 1 have the same total lift if

$$2\int_0^{b/2} C_l c\,dy = C_L S, \qquad (1)$$

and the pitching moment about any axis parallel to OY is the same if

$$2\int_0^{b/2} C_l cx\,dy + 2\int_0^{b/2} C_{m0}c^2\,dy = C_L\bar{x}S + \overline{C}_{m0}\bar{c}S \qquad (2)$$

Now, writing

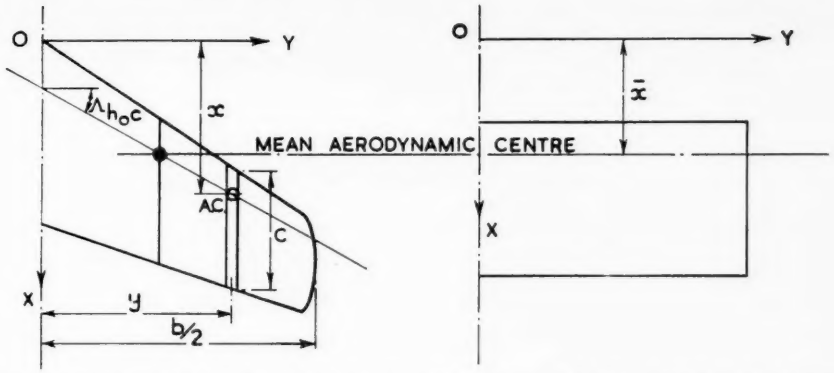
$$C_l = C_{la} + C_{lb}$$

(where C_{lb} is the local lift coefficient when the total wing lift is zero, *i.e.* the "basic" lift coefficient; C_{la} is the "additional" lift coefficient due to incidence), equation (1) can be written

$$2\int_0^{b/2} C_{la} c\,dy = C_L S,$$

since, by definition,

$$2\int_0^{b/2} C_{lb} c\,dy = 0.$$



Swept, tapered and twisted wing of area S, with C_l, C_{m0}, c varying along the span.

Equivalent untwisted rectangular wing of area S, having constant C_L, $\bar{C}_{m0}$, chord $\bar{c}$ and position of aerodynamic centre $\bar{x}$.

Fig. 1.

Then, when the total wing lift is zero

$$2\int_0^{b/2} C_{lb}cxdy+2\int_0^{b/2} C_{m_0}c^2dy=\bar{C}_{m_0}\bar{c}S\,, \qquad . \quad . \quad . \quad (3)$$

and subtracting this from (2) gives

$$2\int_0^{b/2} C_{la}cxdy=C_L\bar{x}S\,. \qquad . \quad . \quad . \quad . \quad (4)$$

These three equations, (1), (3) and (4), define C_L, $\bar{C}_{m_0}$ and $\bar{x}$. Thus from equation (4)

$$\bar{x}=\frac{\int_0^{b/2} C_{la}cxdy}{\int_0^{b/2} C_{la}cdy}=\frac{2\int_0^{b/2} C_{la}cxdy}{C_LS} \qquad . \quad . \quad . \quad . \quad (5)$$

From equation (1),

$$C_L=\frac{2\int_0^{b/2} C_{la}cdy}{S}=\frac{2\int_0^{b/2} C_lcdy}{S} \qquad . \quad . \quad . \quad . \quad (6)$$

$\bar{C}_{m_0}$ is defined by equation (3) and depends on both the distribution of C_{m_0} across the span and on the wing "basic" loading. If there is no "basic" loading,

$$\bar{C}_{m_0}=\frac{\int_0^{b/2} C_{m_0}c^2dy}{\bar{c}S}$$

and $\bar{\bar{c}}$ must therefore be defined by

$$\bar{\bar{c}} = \frac{\int_0^{b/2} c^2 dy}{\int_0^{b/2} c dy} = \frac{2\int_0^{b/2} c^2 dy}{S} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

The chord $\bar{\bar{c}}$ is called the *mean aerodynamic chord* and the co-ordinate $\bar{x}$ gives the fore-and-aft position of the *mean aerodynamic centre* of the wing. (The aerodynamic centre is the point about which $\partial C_m/\partial C_L = 0$. If the two wings have identical lift and pitching moment about any axis at all incidences then they have the same "mean aerodynamic centre").

The spanwise position of the mean aerodynamic centre of the half wing is given by

$$\bar{y} = \frac{\int_0^{b/2} C_{la} c y dy}{\int_0^{b/2} C_{la} c dy} = \frac{2\int_0^{b/2} C_{la} c y dy}{C_L S} \quad . \quad . \quad . \quad . \quad . \quad (8)$$

The equivalent rectangular wing thus has a chord length $\bar{\bar{c}}$, span $S/\bar{\bar{c}}$, and is placed so that its aerodynamic centre is distant $\bar{x}$ behind the datum. It will be noted that $\bar{x}$ depends on the additional load distribution so that the position of the true "mean aerodynamic centre" varies with wing incidence if the form of the additional loading varies with incidence (*e.g.* if the section lift curve slope varies along the wing) and thus it may be of limited use as a standard.

There is one exception to this. If the local aerodynamic centres lie in a straight line which is unswept ($x = \bar{x} =$ constant), the fore-and-aft co-ordinate of the mean aerodynamic centre is independent of the form of the loading distribution. The difficulty about the use of "mean aerodynamic centre" as a datum arises, therefore, only when the wing is swept.

If the wing has no aerodynamic twist the mean aerodynamic centre of the half wing is also the *centre of pressure* of the half wing. If there is a "basic" loading (*i.e.* at zero overall lift, due to wing twist), then $(\bar{x}, \bar{y}^*)$ is the centre of pressure of the "additional" loading.

3. POSITION OF "MEAN AERODYNAMIC CENTRE"

The spanwise position (y) of the local aerodynamic centre is known exactly, and from equation (8) the spanwise position of the "mean aerodynamic centre" of the half wing can be calculated, once the "additional" spanwise loading distribution is known. Stanton-Jones[12] gives a method of finding both of these for a trapezoidal wing†.

It is, however, the fore-and-aft position ($\bar{x}$) of the mean aerodynamic centre which is required in longitudinal stability calculations. Equation (5) is used to calculate $\bar{x}$ from the spanwise "additional" loading distribution, but the fore-and-aft position (x) of each local aerodynamic centre must be known first. When it is assumed that all aerodynamic centres lie on the quarter-chord line (or, to be slightly

*The co-ordinate $\bar{y}$ is sometimes written $\eta_{c.p.}\, b/2$.

†Stanton-Jones obtains the empirical formula.

$$\eta_{c.p.} = 0.42 + \frac{A}{10^3}\left[(4.4 + 5\lambda)\tan\Lambda_{c/4} + 10.4\lambda^3 - 6.7\right].$$

more general, on the h_0c line), then the spanwise position of the mean aerodynamic centre is sufficient to locate it, since $\bar{x}=\bar{y}\tan\Lambda_{h_0c}$.

Experiment supported by calculations based on lifting surface theory shows, however, that the locus of local aerodynamic centres is not a straight line, particularly on swept wings. The position of the aerodynamic centre varies from about 0.35 at the root to 0.15 at the tip expressed as a fraction of the local chord. Analyses have been made of the available data and more are in progress to determine the effect of this variation on the fore-and-aft position of the mean aerodynamic centre. It is hoped that an empirical relation can be developed which will give the correction to the co-ordinate $\bar{x}$ in terms of the parameters Λ, A, λ, Mach number, and so on.

Until this correction is known the assumption of a straight swept line of aerodynamic centres has to be accepted unless for the particular case under review theoretical or experimental data are available. Many investigations have in fact assumed that the local aerodynamic centres all lie on the quarter-chord line (*e.g.* Ref. 11).

4. CALCULATION OF MEAN CHORD AND MEAN AERODYNAMIC CENTRE FOR CERTAIN WINGS

In order to illustrate the discrepancies which may occur if the wrong aerodynamic centre is chosen, the length of the chords $\bar{c}$, $\bar{\bar{c}}$ and the position of the mean aerodynamic centre of the half wing $(\bar{x}, \bar{y})$ have been calculated for several plan forms and loading distributions. The detailed calculations are given in the Appendix and the results are given in Table I.

TABLE I

Plan form	*"Additional" loading distribution*	S.M.C. $\bar{c}$	M.A.C. $\bar{\bar{c}}$	*Ratio* $\bar{c}/\bar{\bar{c}}$	*Lateral position of mean aerodynamic centre*	
1. Constant taper and sweep (trapezoidal)	Any	$\frac{c_r}{2}(1+\lambda)$	$\frac{2c_r}{3}\frac{1+\lambda+\lambda^2}{1+\lambda}$	$\frac{3}{4}\frac{1+2\lambda+\lambda^2}{1+\lambda+\lambda^2}$	$\eta_{c.p.}\frac{b^*}{2}$	
2. "	Proportional to wing chord (*i.e.* uniform C_{l_a})	"	"	"	$\frac{b}{2}\frac{1+2\lambda}{3(1+\lambda)}$	Fig. 2
3. "	Elliptic	"	"	"	$\frac{b}{2}\frac{4}{3\pi}$	
4. Elliptic (with straight sweep of line of aerodynamic centres)	Any	$\frac{c_r\pi}{4}$	$\frac{c_r 8}{3\pi}$	$\frac{3\pi^2}{32}=0.927$	$\eta_{c.p.}\frac{b^*}{2}$	
5. "	Elliptic (*i.e.* uniform C_{l_a})	"	"	"	$\frac{b}{2}\frac{4}{3\pi}$	Fig. 3
6. Any (with straight sweep of line of aerodynamic centres)	Elliptic	$\frac{S}{b}$	$\frac{2}{S}\int_0^{+b/2} c^2 dy$	——	"	

$\bar{c}/\bar{\bar{c}}$, $\bar{\bar{c}}/c_r$ and $\bar{y}=\frac{b}{2}\frac{1+2\lambda}{3(1+\lambda)}$ are plotted in Fig. 4.

*The position of the mean aerodynamic centre of the half wing (or centre of pressure of the "additional" load) can be expressed as a simple formula only if the load is of some simple form such as elliptical or proportional to plan form. In the general case the "additional" loading distribution and the position of the spanwise c.p. position must be obtained by a method such as those of Stanton-Jones[12], Weissinger[4] (*see* Section 3).

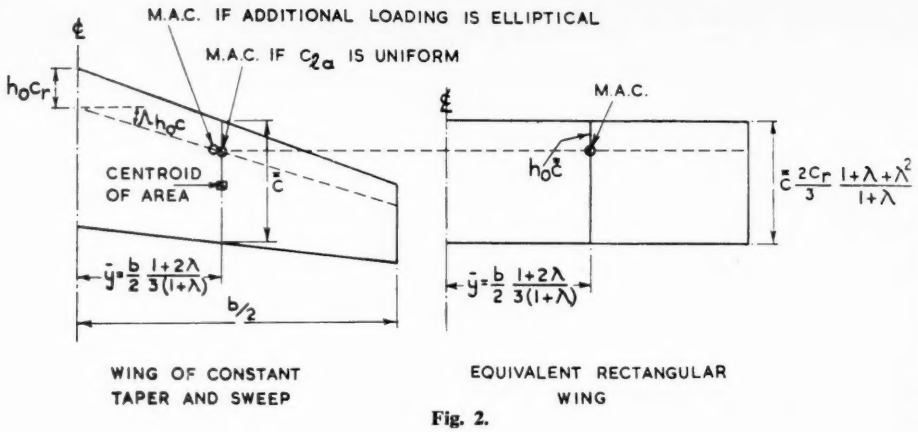


Fig. 2.

5. IDEAL AERODYNAMIC CENTRE

The co-ordinates of the mean aerodynamic centre of a wing are thus given by equations (5) and (8) and depend on the "additional" loading distribution. In the special case when the "additional" loading is elliptic and the local aerodynamic centre is everywhere at the quarter-chord point, it is shown in the Appendix that

$$\left.\begin{aligned}\bar{x}&=\frac{c_r}{4}+\frac{b}{2}\frac{4}{3\pi}\tan\Lambda_{c/4}\\ \bar{y}&=\frac{b}{2}\frac{4}{3\pi}.\end{aligned}\right\}$$

Falkner[1] has called this position the "ideal aerodynamic centre."

6. STANDARD MEAN CHORD

The Standard Mean Chord of a half wing, as defined in A.P.970, has length $\bar{c}=S/b$ (also called the geometric or average chord) and is placed with its quarter-chord point at the "mean quarter-chord point"

$$\bar{x}_{1/4}=\frac{\int_0^{b/2} cx_{1/4}dy}{\int_0^{b/2} cdy}, \quad \bar{y}_{1/4}=\frac{\int_0^{b/2} cy_{1/4}dy}{\int_0^{b/2} cdy}.$$

In general, this is not the mean aerodynamic centre, nor is the length of the local chord through the point $\bar{x}_{1/4}, \bar{y}_{1/4}$ equal to $\bar{c}$.

7. CENTROID OF AREA CHORD

It happens that the mean aerodynamic chord of a half wing having a uniform taper and sweep (trapezoidal half wing) equals in length the chord through the

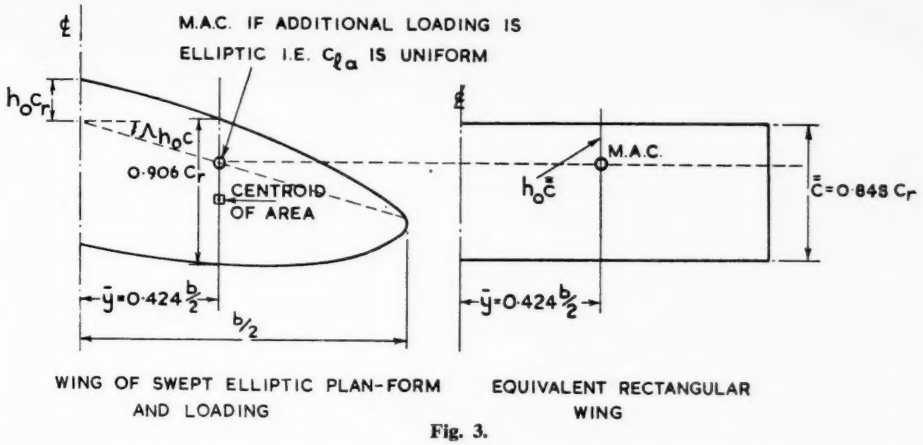


Fig. 3.

centroid of area of the half wing. If the local "additional" lift coefficient is constant along the span, then the aerodynamic centre is also on this chord. Several American reports* use the centroid of area chord as a reference chord.

8. GEOMETRICAL RELATIONS FOR THE WING OF UNIFORM TAPER AND SWEEP

(*i*) *Relation between the angles of sweep of various chord lines*

The straight line joining the points distant hc from the wing leading edge has a sweep angle Λ_{hc} given by

$$\tan \Lambda_{hc} = \frac{(b/2)\tan \Lambda_{LE} - h(c_r - c_t)}{b/2}$$

$$= \tan \Lambda_{LE} - h\frac{c_r}{b/2}(1-\lambda),$$

i.e.
$$\tan \Lambda_{hc} = \tan \Lambda_{LE} - h\frac{4}{A}\frac{1-\lambda}{1+\lambda}. \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Similarly
$$\tan \Lambda_{LE} = \tan \Lambda_{c/4} + \frac{1}{A}\frac{1-\lambda}{1+\lambda} \quad . \quad . \quad . \quad . \quad . \quad (10)$$

$$\tan \Lambda_{TE} = \tan \Lambda_{c/4} - \frac{3}{A}\frac{1-\lambda}{1+\lambda} \quad . \quad . \quad . \quad . \quad . \quad (11)$$

For wings of straight trailing edge

$$\tan \Lambda_{c/4} = \frac{3}{A}\frac{1-\lambda}{1+\lambda} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

and for the delta wing ($\lambda = 0$)

$$\tan \Lambda_{c/4} = \frac{3}{A} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

e.g. De Young[11]. "This chord which passes through the centroid of wing area is the true M.A.C. if the local C_l is constant along the span. It is nearly the same as the true M.A.C. for moderate sweeps."

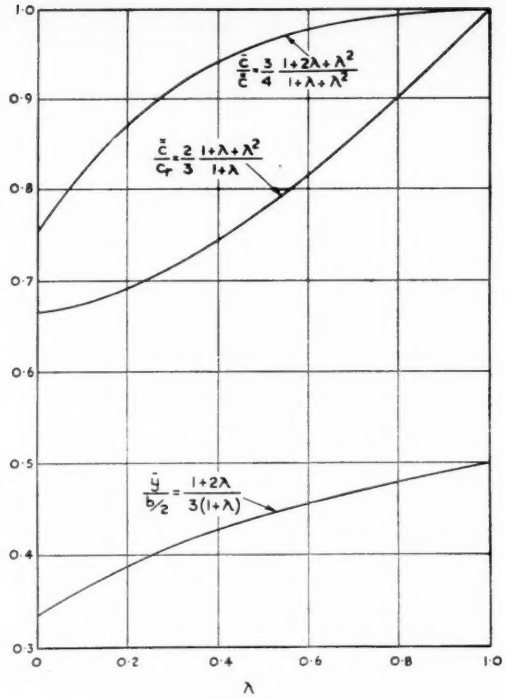


Fig. 4.

9. THE RELATION BETWEEN THE CO-ORDINATES OF A GIVEN POINT WHEN REFERRED TO THE S.M.C. AND TO THE M.A.C.

It has been shown that aerodynamic calculations (*e.g.* of the mean aerodynamic centre, neutral points) should be referred to the M.A.C., $\bar{c}$, as reference. It often happens that other points (such as the c.g. which is needed to calculate static margin) are referred to the S.M.C. as reference. A relation between the x-co-ordinate in the two systems is required.

(*i*) The relation between the co-ordinates h of any position G in the two systems is (Fig. 5)

$$(h_{\text{SMC}} - 1/4)\bar{c} + \bar{x}_{\text{SMC}} = (h_{\text{MAC}} - h_0)\bar{c} + \bar{x}_{\text{MAC}} \quad . \quad . \quad . \quad . \quad (14)$$

In the special cases

(*ii*) C_{l_α} *constant along span*

the quarter-chord point of S.M.C. and the aerodynamic centre of M.A.C. are at the same point, $\bar{x} = \int cxdy \Big/ \int cdy$, and the relation between any position G in the two systems is

$$(h_{\text{SMC}} - 1/4)\bar{c} = (h_{\text{MAC}} - h_0)\bar{c} \quad . \quad . \quad . \quad . \quad . \quad (15)$$

(*iii*) *Elliptic loading*

In this case

$$\bar{x}_{SMC}-\bar{x}_{MAC}=\frac{b}{2}\tan\Lambda_{h_0e}\left(\frac{1+2\lambda}{3(1+\lambda)}-\frac{4}{3\pi}\right)$$

which is zero only if $\lambda=0.376$.

The relation is, generally,

$$(h_{SMC}-1/4)\bar{c}=(h_{MAC}-h_0)\bar{\bar{c}}+\frac{b}{2}\tan\Lambda_{h_0e}\left(\frac{4}{3\pi}-\frac{1+2\lambda}{3(1+\lambda)}\right) \quad . \quad (16)$$

10. LOCATION OF THE CENTRE OF PRESSURE OF THE "ADDITIONAL LOAD" (MEAN AERODYNAMIC CENTRE) RELATIVE TO THE MEAN AERODYNAMIC CHORD OF A WING OF UNIFORM TAPER AND SWEEP

For this wing the mean aerodynamic chord (M.A.C., $\bar{\bar{c}}$) is the same as the centroid of area chord (C.A.C.), but the centre of pressure of the "additional" load on the half wing is not on this chord unless the "additional" lift coefficient happens to be constant along the span (Table I). In general, the c.p. is at $\bar{y}=\eta_{c.p.}b/2$ and may be assumed to be on the line of aerodynamic centres, so that

$$\bar{x}=h_0c_r+\frac{b}{2}\eta_{c.p.}\tan\Lambda_{h_0e}.$$

It is sometimes necessary to refer the c.p. to the M.A.C. (C.A.C.) and a formula is now obtained giving the fore-and-aft position of the c.p. relative to this chord ($h_{c.p.}$).

Now
$$\bar{\bar{c}}=\frac{2c_r}{3}\frac{1+\lambda+\lambda^2}{1+\lambda}$$

and the length of chord at the c.p. is

$$c_{c.p.}=c_r[1-(1-\lambda)\eta_{c.p.}].$$

Now
$$h_{c.p.}\bar{\bar{c}}=h_0\bar{\bar{c}}+\left(\eta_{c.p.}\frac{b}{2}-\bar{y}\right)\tan\Lambda_{h_0e} \quad \text{(Fig. 6)}$$

i.e.
$$h_{c.p.}=h_0+\frac{b}{2}\tan\Lambda_{h_0e}\frac{\left[\eta_{c.p.}-\dfrac{1+2\lambda}{3(1+\lambda)}\right]}{\dfrac{2c_r}{3}\dfrac{1+\lambda+\lambda^2}{1+\lambda}}.$$

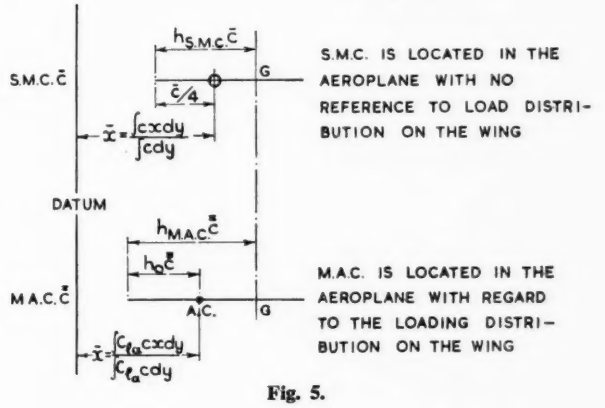


Fig. 5.

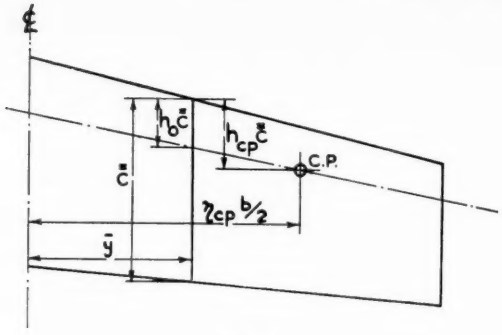


Fig. 6.

Therefore $$h_{c.p.}=h_0+A\tan\Lambda_{h0c}\frac{3(1+\lambda)^2}{8(1+\lambda+\lambda^2)}\left[\eta_{c.p.}-\frac{1+2\lambda}{3(1+\lambda)}\right] \quad . \quad . \quad (17)$$

This is the formula used by De Young[11].

APPENDIX

1. DERIVATION OF THE RESULTS GIVEN IN TABLE I

Wing of constant taper and sweep as shown in Fig. 7

The length of the chord at spanwise distance y (Fig. 7) is

$$c=\frac{c_r(\frac{1}{2}b-y)+c_t y}{b/2},$$

i.e. $$c=c_r\left[1-\frac{y}{b/2}(1-\lambda)\right] \quad . \quad . \quad . \quad . \quad . \quad (18)$$

where $\lambda=c_t/c_r$, the wing taper ratio.

Thus $$\bar{c}=\frac{\int_0^{b/2}c^2dy}{\int_0^{b/2}cdy}$$

$$=\frac{\int_0^{b/2}c_r^2\left[1-\frac{y}{b/2}(1-\lambda)\right]^2dy}{(b/4)(c_r+c_t)}$$

$$=\frac{c_r^2(b/2)(1+\lambda+\lambda^2)/3}{(b/4)(c_r+c_t)},$$

i.e. $$\bar{c}=\frac{2c_r}{3}\frac{1+\lambda+\lambda^2}{1+\lambda} \quad . \quad . \quad . \quad . \quad . \quad (19)$$

is the length of the *mean aerodynamic chord*.

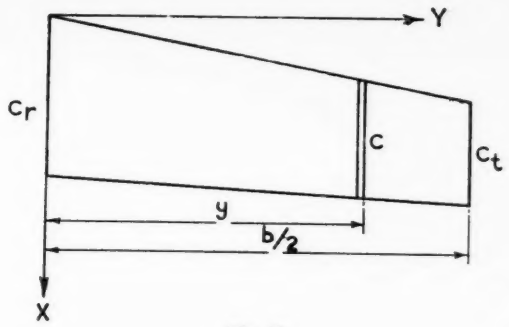


Fig. 7.

Centroid of area chord

The lateral co-ordinate of the centroid of area of the half wing is

$$\bar{y}=\frac{\int_0^{b/2} cy\,dy}{\int_0^{b/2} c\,dy}$$

Substituting for c from equation (18) and integrating, gives

$$\bar{y}=\frac{b}{2}\,\frac{1+2\lambda}{3(1+\lambda)} \qquad . \quad . \quad . \quad . \quad (20)$$

The length of the chord at this lateral position is given by equation (18) as

$$c=c_r\left[1-\frac{1+2\lambda}{3(1+\lambda)}(1-\lambda)\right].$$

i.e.

$$c=\frac{2c_r}{3}\,\frac{1+\lambda+\lambda^2}{1+\lambda}. \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (21)$$

Thus the length of the chord through the centroid of area of the half wing is the same as the "*mean aerodynamic chord*," $\bar{\bar{c}}$.

$\bar{\bar{c}}$ is, therefore, sometimes referred to as the "*centroid of area chord*."

The "*standard mean chord*" ($\bar{c}$=area/span) has the length

$$\bar{c}=\frac{c_r}{2}(1+\lambda) \qquad . \quad . \quad . \quad . \quad . \quad (22)$$

so that

$$\bar{c}/\bar{\bar{c}}=\frac{3}{4}\,\frac{1+2\lambda+\lambda^2}{1+\lambda+\lambda^2}. \qquad . \quad . \quad . \quad . \quad (23)$$

It is seen that the "mean aerodynamic chord," $\bar{\bar{c}}$, is usually slightly longer than the "standard mean chord," $\bar{c}$. The ratio varies with taper ratio as follows (*see* Fig. 4).

λ	1	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{4}$
$\frac{\bar{c}}{\bar{\bar{c}}}$	1.000	0.964	0.923	0.893

2. POSITION OF THE MEAN AERODYNAMIC CENTRE (ASSUMING UNIFORM SPANWISE "ADDITIONAL" LIFT COEFFICIENT).

From equation (5), the x-co-ordinate of the mean aerodynamic centre for uniform spanwise "additional" lift coefficient is

$$\bar{x}=\frac{\int_0^{b/2} cx\,dy}{\int_0^{b/2} c\,dy}$$

where x is the co-ordinate of the local aerodynamic centre.

If the aerodynamic centre is at the position h_0 all along the span then, referred to the root leading edge as datum point,

$$x=y\tan\Lambda_{h_0e}+h_0c_r\,,$$

and from equation (18)

$$c=c_r\left[1-\frac{y}{b/2}(1-\lambda)\right].$$

After making these substitutions into equation (7) and integrating,

$$\bar{x}=h_0c_r+\frac{b}{2}\,\frac{1+2\lambda}{3(1+\lambda)}\tan\Lambda_{h_0e}. \qquad . \quad . \quad . \quad . \quad . \quad (24)$$

[If the aerodynamic centre is at the quarter-chord point this becomes

$$\bar{x}=\frac{c_r}{4}+\frac{b}{2}\,\frac{1+2\lambda}{3(1+\lambda)}\tan\Lambda_{c/4} \qquad . \quad . \quad . \quad . \quad (24a)]$$

It should be noted that the chord which has its aerodynamic centre at this x-co-ordinate is the one at

$$y=\frac{b}{2}\,\frac{1+2\lambda}{3(1+\lambda)}, \qquad . \quad . \quad . \quad . \quad . \quad (25)$$

i.e. the chord through the *centroid of area.*

In this case, therefore, the mean aerodynamic centre lies on the same chord line as the centroid of area and the length of the local chord equals $\bar{c}$.

3. POSITION OF THE MEAN AERODYNAMIC CENTRE (ASSUMING ELLIPTIC "ADDITIONAL" LOADING)

Writing $\qquad \frac{y}{b/2}=\eta=\sin\theta\,,$

we have $\qquad C_{la}c\propto\sqrt{(1-\eta^2)}$

and
$$\bar{x}=\frac{\int_0^{b/2} C_{la}cx\,dy}{\int_0^{b/2} C_{la}c\,dy}$$

$$=\frac{b}{2}\tan\Lambda_{hoc}\frac{\int_0^1\sqrt{(1-\eta^2)}\,\eta\,d\eta}{\int_0^1\sqrt{(1-\eta^2)}\,d\eta}$$

$$=\frac{b}{2}\tan\Lambda_{hoc}\frac{\int_0^{\pi/2}\cos^2\theta\sin\theta\,d\theta}{\int_0^{\pi/2}\cos^2\theta\,d\theta},$$

i.e.
$$\bar{x}=\frac{4}{3\pi}\frac{b}{2}\tan\Lambda_{hoc}$$

$$=0.424\frac{b}{2}\tan\Lambda_{hoc}, \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

so that
$$\bar{y}=\frac{4}{3\pi}\frac{b}{2}=0.424\frac{b}{2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

4. WING OF ELLIPTIC PLAN FORM

Now
$$c=c_r\sqrt{(1-\eta^2)}$$

so that
$$\bar{\bar{c}}=\frac{\int_0^{b/2}c^2dy}{\int_0^{b/2}cdy}=\frac{\int_0^1(1-\eta^2)\,d\eta}{\frac{\pi}{4}\frac{b}{2}c_r}.$$

Therefore
$$\bar{\bar{c}}=\frac{8}{3\pi}c_r=0.848\,c_r. \quad . \quad . \quad . \quad . \quad . \quad . \quad (28)$$

Now
$$\bar{c}=\frac{\pi}{4}c_r=0.785\,c_r \quad . \quad . \quad . \quad . \quad . \quad . \quad (29)$$

so that
$$\bar{c}/\bar{\bar{c}}=\frac{3\pi^2}{32}=0.927. \quad . \quad . \quad . \quad . \quad . \quad . \quad (30)$$

The *centroid of area* of the half wing has the co-ordinate
$$\bar{y}=\frac{\int_0^{b/2}cydy}{\int_0^{b/2}cdy}=\frac{\frac{b}{2}\int_0^{\pi/2}\cos^2\theta\sin\theta\,d\theta}{\pi/4}$$

and therefore
$$\bar{y}=\frac{4}{3\pi}\frac{b}{2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (31)$$

The length of the chord through the centroid of area is

$$c = c_r \sqrt{\left[1 - \left(\frac{4}{3\pi}\right)^2\right]} = 0.906\, c_r \qquad . \quad . \quad . \quad (32)$$

Thus, for the elliptic wing, the chord through the centroid of area is *not* the same length as the mean aerodynamic chord, but the mean aerodynamic centre for elliptic loading and the centroid of area both lie on the chord at $\bar{y} = (4/3\pi)(b/2)$ (*see* Fig. 3).

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2297—*Lateral response theory. K. Mitchell.*
2338—*Relaxation time effects in gas dynamics. J. C. Gunn.*
2385—*Tunnel blockage near the choking condition. A. Thom and Myra Jones.*
2421—*Wings of finite aspect ratio at supersonic velocities. D. R. Taunt and G. N. Ward.*
2471—*Strain gauge flutter tests on a 4-blade propeller with duralumin blades. J. Kettlewell and H. G. Ewing.*
2473—*The validity of full-scale propeller braking tests in the R.A.E. 24-ft. wind tunnel. A. B. Haines and R. J. Monaghan.*
2475—*Wind-tunnel tests on the 30 per cent. symmetrical Griffith aerofoil with ejection of air at the slots. N. Gregory, W. S. Walker and W. G. Raymer.*
2483—*The effect of pointed tips on wing loading calculations. V. M. Falkner.*
2489—*Flight measurements of the pressure distribution on a Tempest wing up to a Mach number of 0.8. K. Eyre.*
2493—*24-ft. wind-tunnel tests on a "paddle-blade" propeller. A. B. Haines.*
2501—*Supersonic diffusers. J. Lukasiewicz.*
2502—*Note on the Frise aileron. H. H. B. M. Thomas and E. R. Crabbe.*
2552—*The prevention of binary flutter by artificial damping. R. A. Frazer.*

2553—*Possio's subsonic derivative theory and its application to flexural-torsional wing flutter. Part I. R. A. Frazer. Part II. R. A. Frazer and Sylvia W. Skan.*
2558—*Wind-tunnel tests on the spoiling effects of engine cooling gills on radial air-cooled installations on a wing. J. Seddon and J. A. Kirk.*
2616—*The flow in an axially-symmetric supersonic jet from a nearly-sonic orifice into a vacuum. P. L. Owen and C. K. Thornhill.*
2672—*On a theory of sandwich construction. W. S. Hemp.*
2708—*Tank tests on a hull with the main step faired in planform and elevation. D. I. T. P. Llewelyn-Davies.*
2711—*Tests on a model body-wing combination at supersonic speed. P. J. Wingham.*
2719—*A method for determining the water stability of a seaplane in take-off and landing. H. G. White and A. G. Smith.*

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F.91—*Theory of the calculation of load-distribution for yawed and swept wings in incompressible flow. A. van Heemert.*
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1008—*A small-deflection theory for curved sandwich plates. M. Stein and J. Mayers.*
1015—*Analysis of turbulent free-convection boundary layer on flat plate. E. R. G. Eckert and T. W. Jackson.*
1017—*Investigation of frequency-response characteristics of engine speed for a typical turbine-propeller engine. B. L. Taylor, III and F. L. Oppenheimer.*
1019—*Relation between inflammables and ignition sources in aircraft environments. W. E. Scull.*
1020—*Measurements of average heat-transfer and friction coefficients for subsonic flow of air in smooth tubes at high surface and fluid temperatures. L. V. Humble, W. H. Lowdermilk and L. G. Desmon.*

Technical Notes.

2594—*Investigation of the structural damping of a full-scale airplane wing. D. O. Fearnow.*
2620—*Principle and application of complementary energy method for thin homogeneous and sandwich plates and shells with finite deflections. Chi-Teh Wang.*
2628—*Bonding of molybdenum disulfide to various materials to form a solid lubricating film. 1—The bonding mechanism. D. Godfrey and E. E. Bisson.*
2629—*Analytical and experimental investigation of fully developed turbulent flow of air in a smooth tube with heat transfer with variable fluid properties. R. G. Deissler and C. S. Eian.*

2630—*A solution of the Navier-Stokes equation for source and sink flows of a viscous heat-conducting compressible fluid. R. V. Hess.*
2631—*The similarity law for nonsteady hypersonic flows and requirements for the dynamical similarity of related bodies in free flight. F. M. Hamaker and T. J. Wong.*
2633—*Estimation of the maximum angle of sideslip for determination of vertical-tail loads in rolling maneuvers. R. W. Stone, Jr.*
2634—*Evaluation of three methods for determining dynamic characteristics of a turbojet engine. G. J. Delio.*
2635—*An analysis of laminar free-convection flow and heat transfer about a flat plate parallel to the direction of the generating body force. S. Ostrach.*
2636—*Influence of lubricant viscosity on operating temperatures of 75-millimeter-bore cylindrical-roller bearing at high speeds. E. F. Macks, W. J. Anderson and Z. N. Nemeth.*
2637—*Compressive buckling of flat rectangular Metalite type sandwich plates with simply supported loaded edges and clamped unloaded edges. (Revised.) P. Seide.*
2638—*Study of inadvertent speed increases in transport operation. H. A. Pearson.*
2639—*Fatigue strengths of aircraft materials. Axial-load fatigue tests on notched sheet specimens of 24S-T3 and 75S-T6 aluminum alloys and of SAE 4130 steel with stress-concentration factor of 1.5. H. J. Grover, W. S. Hyler and L. R. Jackson.*
2642—*Application of linear analysis to an experimental investigation of a turbojet engine with proportional speed control. M. Dandois and D. Novik.*
2645—*Effects of wing lift and weight on landing-gear loads. D. C. Lindquist.*
2646—*Inviscid flow about airfoils at high supersonic speeds. A. J. Eggers, Jr., and C. A. Syvertson.*
2647—*Implication of the transport equation for the semi-empirical treatment of shields. P. Schwed.*
2648—*Experimental investigation of transition of a model helicopter rotor from hovering to vertical autorotation. S. R. Slaymaker, R. R. Lynn and R. B. Gray.*
2649—*Effect of Mach number on the flow and application of compressibility corrections in a two-dimensional subsonic-transonic compressor cascade having varied porous-wall suction at the blade tips. W. B. Briggs.*
2650—*Radioautographic method for examining distribution of particles in a cyclotron beam. M. L. Pool and S. Fultz.*
2651—*Supersonic conical flow. S. H. Maslen.*
2652—*Application of a channel design method to high-solidity cascades and tests of an impulse cascade with 90° of turning. J. D. Stanitz and L. J. Sheldrake.*
2653—*A thermodynamic study of the turbine-propeller engine. B. Pinkel and I. M. Karp.*
2654—*Two-dimensional flow on general surfaces of revolution in turbomachines. J. D. Stanitz and G. O. Ellis.*
2655—*Critical study of integral methods in compressible laminar boundary layers. P. A. Libby, M. Morduchow and M. Bloom.*
2658—*Laminar boundary layer over flat plate in a flow having circular streamlines. A. Mager and A. G. Hansen.*
2664—*Experimental investigation of the turbulent-boundary-layer temperature-recovery factor on bodies of revolution at Mach numbers from 2.0 to 3.8. H. A. Stine and R. Scherrer.*
2666—*Two-dimensional subsonic flow past elliptic cylinder by the variational method. G. V. R. Rao.*

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1300—*Wind-tunnel corrections at high subsonic speeds, particularly for an enclosed circular tunnel. S. Gothert.*
1328—*Concerning the flow about ring-shaped cowlings. Part VIII—Further measurements on annular profiles. D. Kuchemann and Johanna Weber.*
1329—*Concerning the flow about ring-shaped cowlings. Part IX—The influence of oblique oncoming flow on the incremental velocities and air forces at the front part of circular cowls. D. Kuchemann and Johanna Weber.*
1333—*On rotational conical flow. C. Ferrari.*
Thirty-seventh Annual Report. 1951.

CORRESPONDENCE

PRODUCTION RESEARCH

Mr. Bunnett's "warning" ("Production Research on Aircraft," March 1952 JOURNAL), is most opportune. The urgency of the present economic situation and the acute shortage of technical personnel demand a critical self-examination and self-analysis on the part of the Aircraft Industry.

A method of approach to such an examination and analysis has been suggested by Mr. Bunnett. He indicates many defects in the Industry, but not in proper relation to the many variable factors upon which they are dependent. He states various needs but not in clearly defined perspective; furthermore, other essential needs have not even been perceived and have yet to be recognised. Unless these needs can be perceived, identified, located, studied, and analysed in relation to other needs, intra-industry and inter-industry, and with respect to the organisational structure of the individual firm then a hit-and-miss method will still prevail instead of a scientific and methodical approach to the problem. Mr. Bunnett does indicate the need for " Organisational Research " and " Integrated Training " which is becoming increasingly imperative. However, unless I am under the mistaken impression that his paper is not restricted to factory organisation, his approach is too limited, though indicative of the right trend.

The aircraft firm is a business unit within a complex economic system, and as such it should be examined as an entity from every aspect of organisational departmentation, direction, and control; that is, it should be examined analytically rather than synthetically.

The synthetic approach presupposes the existence of adequate organisational direction and control which may not be present. It is a method of strengthening the weak links in a chain that are easily discernible. In the process, those that are not so easily discernible may be neglected, and complete gaps in the chain may be completely overlooked. In consequence, separate research on individual elements within the business unit may not reveal important relationships with other elements, tangible or intangible. Increased productivity might be achieved, but not as much as that which could be attained; and permanent harm, in industrial relations for example, might result.

The analytical approach on the other hand does not presuppose the existence of a well-knit, well-balanced, and smooth functioning business organisation. If the organisation is defective, this approach will reveal the flaws and uncover the important elements that may be missing. Consequently, in subsequent research on individual elements, the likelihood of overlooking any important factors or relationships is considerably reduced. The analytical approach ensures that from every aspect of direction and control maximum possible productivity is attained. A " static " organisational structure is not conducive to progress, efficiency, and success; particularly in meeting greater and greater national demands, and in coping with the ever increasing competitive conditions in the world economic situation. The organisational structure should be flexible, should be kept under constant review, and any defects redeemed and weaknesses rectified. The structure can then be most advantageously strengthened by strengthening its separate elements.

These observations suggest a few comments upon Mr. Bunnett's " Education for Management " in which he stated that " In the United States . . . the opportunities for education in management are limited." Mr. Bunnett may be interested to know that universities in the United States, other than those he mentioned, offer degree courses in industrial engineering, the curricula of which include, *inter alia*, economics, business organisation, general accounting, cost accounting, modern corporation finance, financial institutions, business law, industrial organisation and management, production control, methods analysis, personnel administration, and industrial psychology. (In 1949 there were 47 Colleges and Universities in the U.S.A. with accredited curricula in Industrial Engineering.) The industrial engineering courses are open to graduates in engineering only. Many aeronautical engineering graduates have undertaken this training (including myself).

ALDRIC B. AU-YONG, *Graduate.*

Mr. L. E. Bunnett's paper covers a wide and comparatively new field so well that it may seem ungracious to criticise particular points. But the ones I have in mind are rather striking and I believe the author would prefer to dispel any confusion arising.

In the section of the paper on "Forward Planning" it is stated, very surprisingly, that "historical records of past achievements . . . will be essential means of arriving at . . . an

estimate of the total manhours of the product required for forward planning"; further, that "historical records are the only bases . . . for such estimates."

These statements are in flat contradiction to my own experience in introducing planned maintenance to the Royal Air Force, during which it was shown that past records were useless as a basis for *planning*, and gave only a general expectancy of what might result if things were left as they were. This was confirmed by the U.S. Air Force in almost identical terms. But there is no need of example to support the well established principle that if work is to be planned and controlled it must be method and time studied, and past performance is irrelevant. The development of the Methods-Time-Measurement and the Work Factor systems in America now remove planning even further from any dependence on even current experience, let alone history. It was in this sense that Henry Ford truly said that "history is bunk."

S. D. McDONALD, *Associate Fellow.*

MR. BUNNETT'S REPLY

Mr. McDonald has raised an interesting point which allows me to expand my paper under the heading of "Forward Planning." My reference was, of course, to planning ahead at a time when no detail drawings are available. At this stage there is probably no more than an outline arrangement drawing of the aeroplane or engine with some notion of overall dimensions and weights, but it is essential to have some intelligent idea of the total floor space, the total labour force, the number of machine tools and jigs and tools which will be required.

All such estimates must depend entirely on empirical formulae derived from past or historical data.

From my personal experience in the U.S.A. I can assure Mr. McDonald that, with full respect to the memory of Henry Ford, far more careful analysis of past records is made both in the U.S. Air Force, Air Materiel Command and American industry from which trends can be seen and future planning done, than is to be found in this country.

If an R.A.F. unit is planning a forward programme of maintenance on a new type which has not yet been delivered, it must inevitably base its estimates by comparison in broad terms with past records of similar, or sometimes dissimilar, types.

None of this argument is intended to imply that as and when more detail information comes along, and certainly when production begins, the most up-to-date mechanisms of work-study, motion-study, time-study or M.T.M., should be ignored.

I hope these remarks will dispel any confusion. Planning is a fluid process and is never completed: there is forward planning, such as I have been discussing, before any detail design has been done; there is pre-planning as the detail drawings flow from the drawing office and there is re-planning which should continue until the finish of production in an unceasing endeavour to maintain control and increase productivity.

Many of the American plants include a pre-production or pilot shop in which all jigs and tools are proved and each production detail is made and assembled before the methods or processes are approved for use in the production shops. This enables the fullest application to be made of the work-study methods, mentioned by Mr. McDonald, without disturbing production.

It should be added that the quantity to be produced must dictate the amount of planning which is done. I am sure Mr. McDonald would not suggest applying Methods-Time-Measurement to a Brabazon.

May I take this opportunity of correcting an error which, despite scrupulous checking, has crept into the ante-penultimate paragraph of my printed paper (p. 188): One per cent. of £360,000 is £3,600 and not £36,000.

L. E. BUNNETT, *Associate Fellow.*

APPOINTMENTS

This page of the JOURNAL is available for advertisements of appointments in the Industry, the Ministries, Universities and Colleges. The charge for advertisements for each inch, or part of an inch, in depth is £2 10s. 0d.

MINISTRY OF SUPPLY invites applications for a limited number of **SENIOR** and **JUNIOR FELLOWSHIPS** tenable for two or three years at the Royal Aircraft Establishment, Farnborough. Fellows will be required to carry out fundamental research in aerodynamics or aeronautical structures, the subjects being selected according to the training and experience of the Fellows and the needs of the Establishment. Candidates must be British subjects and Honours graduates in Natural Science. Candidates for Junior Fellowships should normally have had at least two years' post-graduate research experience and should preferably be aged 23-26; for Senior Fellowships they should have had at least three years' post-graduate research experience and should preferably be aged 26-30. Remuneration will depend on individual merit and will be between £800-£1,000 per annum for Senior Fellows and £500-£700 per annum for Junior Fellows. Fellowships carry F.S.S.U. benefits. At the expiry of a Fellowship the holder may be considered for a permanent post at the Establishment if he so desires. Application forms are obtainable from the Director, Royal Aircraft Establishment, Farnborough, Hants., to whom completed forms, together with suitable testimonials regarding research ability and, where possible, copies of candidates' published papers, must be returned by 15th July 1952. Overseas candidates should submit written applications stating age, nationality and place of birth of self and parents, educational and academic qualifications, appointments held and research experience.

PRODUCTION PROJECT OFFICERS required by **MINISTRY OF SUPPLY** at Kingston and Weybridge, Surrey; Hayes, Middx.; Preston, Lancs.; and South Marston, nr. Swindon, for approximately two years. The Hayes post involves periodical vists to Stockport. **Duties:** To speed the introduction of Super-Priority aircraft into service. Each officer will be allocated one aircraft type, and be responsible for clearing major production problems at the parent firm, its subsidiaries and sub-contractors. **Qualifications:** British, of British parentage; recognised engineering apprenticeship; corporate membership of one of the Institutions of Civil, Mechanical or Electrical Engineers or exempting qualification, or technical and practical training to qualify for corporate membership of the Royal Aeronautical Society; wide knowledge of construction and operation of aircraft and equipment; acquaintanceship with methods of planning, jigging, tooling and progressing, for aircraft production, sound judgment on production problems. **Salary:** Within the range £1,256-£1,536 p.a. Opportunities occur periodically for established pensionable posts. Application forms (Quoting Ref. No. C229/52A), from Ministry of Labour and National Service, Technical and Scientific Register (K), Almack House, 26 King Street, London, S.W.1. Closing date 15th July 1952.

APPLICATIONS are invited by the **MINISTRY OF SUPPLY** for an appointment in the grade of **PRINCIPAL SCIENTIFIC OFFICER** to take charge of two new low speed wind tunnels at an Establishment in Bedfordshire. Responsibilities include the development of experimental technique, the detailed operation of the tunnels and the analysis of test results. Applicants must be at least 31 years of age and possess a 1st or 2nd class honours degree in engineering, physics or mathematics. Considerable experience in experimental aerodynamics, including wind tunnel work is essential. Salary will be assessed according to age, qualifications and experience within the inclusive range £1,033-£1,377 male. Rates for women are somewhat lower. Post is unestablished but carries benefits of F.S.S.U. A house will be available for the successful applicant if married. Application forms obtainable from Technical and Scientific Register (K), Almack House, 26-28 King Street, London, S.W.1, quoting C.303/52A. Closing date 15th July 1952.